The system for suppressing an ambient noise signal which contaminates a desired signal includes a noise pickup detector (21) for detecting the ambient noise signal. A noise discriminator (22) processes the detected noise signal into noise data. A reference noise generator (40) converts the noise data into a reference noise signal. The noise generator (40) automatically adjusts the reference noise signal to correspond with changes in the noise signal as it is being detected. A filter (24) filters the reference noise signal into an error signal which is adapted to remove the noise signal from the contaminated signal. A cross-correlator (42) cross-correlates the contaminated signal with the reference noise signal and adjusts the filter (24) to produce the required error signal.
### FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>Austria</td>
</tr>
<tr>
<td>AU</td>
<td>Australia</td>
</tr>
<tr>
<td>BB</td>
<td>Barbados</td>
</tr>
<tr>
<td>BE</td>
<td>Belgium</td>
</tr>
<tr>
<td>BG</td>
<td>Bulgaria</td>
</tr>
<tr>
<td>BJ</td>
<td>Benin</td>
</tr>
<tr>
<td>BR</td>
<td>Brazil</td>
</tr>
<tr>
<td>CF</td>
<td>Central African Republic</td>
</tr>
<tr>
<td>CG</td>
<td>Congo</td>
</tr>
<tr>
<td>CH</td>
<td>Switzerland</td>
</tr>
<tr>
<td>CM</td>
<td>Cameroon</td>
</tr>
<tr>
<td>DE</td>
<td>Germany, Federal Republic of</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
</tr>
<tr>
<td>FI</td>
<td>Finland</td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
</tr>
<tr>
<td>GA</td>
<td>Gabon</td>
</tr>
<tr>
<td>GB</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>HU</td>
<td>Hungary</td>
</tr>
<tr>
<td>IT</td>
<td>Italy</td>
</tr>
<tr>
<td>JP</td>
<td>Japan</td>
</tr>
<tr>
<td>KP</td>
<td>Democratic People's Republic of Korea</td>
</tr>
<tr>
<td>KR</td>
<td>Republic of Korea</td>
</tr>
<tr>
<td>LI</td>
<td>Liechtenstein</td>
</tr>
<tr>
<td>LK</td>
<td>Sri Lanka</td>
</tr>
<tr>
<td>LU</td>
<td>Luxembourg</td>
</tr>
<tr>
<td>MC</td>
<td>Monaco</td>
</tr>
<tr>
<td>MG</td>
<td>Madagascar</td>
</tr>
<tr>
<td>ML</td>
<td>Mali</td>
</tr>
<tr>
<td>MR</td>
<td>Mauritania</td>
</tr>
<tr>
<td>MW</td>
<td>Malawi</td>
</tr>
<tr>
<td>NL</td>
<td>Netherlands</td>
</tr>
<tr>
<td>NO</td>
<td>Norway</td>
</tr>
<tr>
<td>RO</td>
<td>Romania</td>
</tr>
<tr>
<td>SD</td>
<td>Sudan</td>
</tr>
<tr>
<td>SE</td>
<td>Sweden</td>
</tr>
<tr>
<td>SN</td>
<td>Senegal</td>
</tr>
<tr>
<td>SU</td>
<td>Soviet Union</td>
</tr>
<tr>
<td>TD</td>
<td>Chad</td>
</tr>
<tr>
<td>TG</td>
<td>Togo</td>
</tr>
<tr>
<td>US</td>
<td>United States of America</td>
</tr>
</tbody>
</table>
NOISE SUPPRESSION DURING SEISMIC EXPLORATION

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates in general to the art of noise suppression by a summation process and, more particularly, to a method and apparatus especially adapted to remove interfering, continuously-changing, multi-frequency periodic noise signals from a contaminated seismic signals while they are being detected during seismic exploration.

Description of the Prior Art

A seismic signal detected from the earth includes:

(1) a desired seismic component having amplitude, phase and frequency variations representing seismic information,

(2) an undesirable multi-frequency, electrical power-grid-related noise component, and

(3) other such environmental and instrument-related noise components.

As is well known, in a seismic data acquisition channel, the amplitude of the noise component can be orders of magnitude larger than the amplitude of the seismic component. This fact imposes a reduction in the channel's amplifier gains, resulting in a reduced dynamic range and, hence, a decreased resolution for the overall seismic signal. Such self-imposed reduced gain causes the unavoidable self-generated noise within the channel's amplifiers to increase the channel's noise-to-signal ratio.

Therefore, unless noise is effectively reduced from the contaminated seismic signal, the quality of the
seismic data being acquired during seismic exploration and its subsequent interpretation will deteriorate.

The oldest and yet still the most widely used noise suppressor for seismic channels is the notch filter. Periodic noise becomes attenuated according to the depth and width of the notch filter whose center frequency is nominally set to the fundamental frequency of the predominant noise signal, typically the 60 Hz frequency of the local power grid.

In many geographic areas, however, the second or third harmonic of the 60 Hz signal is the predominant noise frequency. As a consequence, a distinct notch filter is required for each harmonic or subharmonic of the predominant fundamental frequency. Hereinafter, the fundamental frequency and its harmonics and/or subharmonics will be collectively called in short the "noise signal".

Narrow-band analog filters are expensive and difficult to build because they require closely matched components. For this practical reason, most notch filters have a relatively wide bandwidth, say 10 Hz, and cause undesirable phase shifting characteristics in the seismic signal being processed therethrough.

U.S. Patent No. 3,704,444 describes a seismic channel which utilizes its digital data processor network to perform a double function: (1) to process the digitized seismic data in the seismic channel, and (2) to produce a feedback error signal which is subtracted from the incoming analog seismic signal at the input to the seismic channel. It is believed that such a system, because of its inherent structural limitations, would lack flexibility in adapting to multiple and changing noise frequencies. Therefore, such a system even at best would appear to be the equivalent of a notch filter which is suitable for only a single dominant frequency.
The above described and other well known problems, associated with notch filters or their equivalents, have prompted attempts to optimize the entire data acquisition instrumentation within the seismic channel in the hope of being able to eliminate notch filters altogether.

One such approach uses a "line balancer" which usually takes the form of a bridge having a pair of variable impedance arms that are electrically connected between each wire within the seismic cable and ground. These impedances are adjusted to increase the common mode noise rejection at the dominant noise frequency, in order to obtain less contamination of the difference mode signal by the common mode noise signal.

But, working with a large number of line balancers requires tedious and very time-consuming manual adjustments. Also, because ambient noise tends to change continuously, the first-adjusted balancer will require readjustment after the last balancer is adjusted and before seismic energy becomes injected into the ground. Such a procedure can become a never-ending task, especially for a seismic data gathering system having 100 or more seismic channels.

The common mode attenuator is a more recent derivative of the line balancer. It requires amplifying the common mode signal with two separate amplifiers. One amplified signal is applied to one wire of the seismic cable through a resistor, and the other signal is applied to the same wire through a capacitor. The outputs of the two amplifiers are also inverted. One inverted signal is applied to the other wire of the seismic cable through a resistor, and the other inverted signal is also applied to the other wire through a capacitor. The gains for these two common mode amplifiers are determined by correlating the difference mode signal with the common mode signal in order to balance the impedance of the seismic cable at the dominant correlated frequency. But, because the impedance
of a seismic cable constitutes a complex quantity, varying with frequency, temperature, etc., the cable will still remain unbalanced for frequencies other than the correlated frequency.

It has also been proposed to synthesize a nulling signal having a predetermined, fixed, single frequency which is substantially equal to the fundamental frequency of the anticipated periodic noise signal. This nulling signal is manually adjusted to have the desired amplitude and phase. Even at best, only the anticipated predominant fundamental noise frequency may be suppressed with such a nulling signal.

In sum, the known noise-suppression systems still have serious drawbacks, such as: (1) introduction into the seismic channel of substantial distortions in the phase, frequency, and/or amplitude characteristics of the seismic signal being gathered; (2) need for time-consuming manual adjustments; and (3) noise cancellation limited to only a single anticipated predominant fundamental noise frequency.

Effective and practical noise suppression must be capable of removing the harmful effects produced by an unanticipated dominant noise frequency and/or its harmonics and subharmonics with a minimum amount of seismic signal degradation. For example, a notch filter, even when well tuned, attenuates the 60 Hz power grid noise by about 40dB, but does not suppress any harmonics and/or subharmonics thereof. At the same time, the notch filter introduces an undesired phase reversal at the center frequency and modifies the amplitudes of the filtered seismic signals over a bandwidth of about 10 Hz on either side of its center frequency.

It is a broad object of the present invention to provide a novel and effective noise suppressor, which is able to sufficiently suppress the harmful effects on the desired seismic signal caused by a continuously-changing,
multi-frequency noise signal that contaminates the seismic signal component as it is being gathered within each one of the seismic channels during seismic exploration of the earth.

It is a further object to provide such noise suppression without at the same time introducing into the seismic channel substantial distortions in the phase, frequency, and/or amplitude characteristics of the seismic signal being gathered and without requiring time-consuming manual adjustments to the networks within the noise suppression system.

SUMMARY OF THE INVENTION

The novel system suppresses the effect produced by a contaminating ambient noise signal component on a desired seismic signal component being gathered within a seismic channel and allows the seismic channel to produce a noise free seismic signal.

In a broad sense, the novel noise suppression system includes: a noise detector which monitors the contaminating noise signal; a noise discriminator which processes the monitored noise signal into noise data; a reference noise generator which waveshapes the noise data into a reference noise signal; a signal modifier having adjustable parameters which changes the reference noise signal into an error signal having characteristics which enable the error signal to remove the noise signal from the contaminated seismic signal; and a signal comparator which compares the reference noise signal with the uncontaminated seismic signal and changes the signal modifier's parameters to enable the signal modifier to produce the required error signal.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic representation in block diagram form of a preferred embodiment of a single seismic
channel data acquisition system utilizing the noise suppression system of the present invention; and

Fig. 2 is an enlarged block diagram representation of the digital data processor network and of the reference noise generator used in the noise suppression system of Fig. 1.

DETAILED DESCRIPTION OF THE INVENTION

This invention is of particular utility to seismographic exploration of the earth's subsurface, wherein an energy source (not shown) injects into the earth a seismic acoustic energy signal which propagates downwardly and then becomes reflected from various subsurface earth layers or reflectors.

A seismic energy source for land use is typically either a sweep-generator type vibrator, whose sweep signal is a unique wavetrain, or an impulsive energy source.

The reflected acoustic image signals of the energy source return from the deep reflectors to the surface of the earth where they are detected by seismic transducers, such as geophones or the like (not shown), which generate corresponding electric seismic signals, usually in analog form.

Origin of the Contaminating Noise Signal

The invention and its objects will be better understood from a brief description of the origin of the contaminating periodic noise signals which can be traced in part to the groups of geophones that are electrically coupled to a pair of wires 5, 6 of a seismic cable 7 which interconnects geophones, leader cables, couplers, etc. Cable 7 leads to and forms part of a seismic channel 8.

The environment surrounding cable 7 generates ambient electric noise currents which flow into seismic cable 7 through resistive leakage and capacitive coupling between wires 5, 6 and ground. Also, magnetic fields can intercept the coils of the geophones and generate voltages
at their output terminals. As a result, the common mode signal can have frequencies such as exist around electric power lines, electric railways, cathodic systems for protecting steel structures and other objects, such as buried pipelines, etc. These noise frequencies can be fixed or they can change with time.

Wires 5 and 6 in seismic cable 7 can have different impedances to ground, hence different common mode voltages to ground. These unbalanced common mode voltages become converted to difference mode voltages or noise signals between wires 5 and 6. On the other hand, the seismic signals generated by the geophones also appear at the input to seismic channel 8 as difference mode seismic signals between wires 5 and 6.

The impedance of seismic cable 7 to ground is a complex quantity, varying with frequency, temperature, and other environmental and meteorological conditions. Variations in the impedance imbalance of cable 7 cause variations in the common mode and in the difference mode noise signals. Both types of noise signals contaminate the seismic signals detected by the geophones, as is well known in the art.

The incoming contaminated seismic signals to channel 8 are amplified by a preamplifier 9, filtered by a seismic filter 10, sequentially sampled by a sample-and-hold (S/H) network 11, and amplified by a well-known, instantaneous-floating-point (IFP) difference amplifier 12 having a first input 13 which receives the contaminated analog samples from S/H 11. The output signal from the IFP amplifier 12 is converted by analog-to-digital (A/D) converter 14 into digital data that is filtered by an offset digital filter 15 to provide to its output line 16 contaminated digital seismic data. As thus far described, seismic channel 8 is conventional and further description thereof is believed unnecessary.
General Description of the Suppression System

It is the object of this invention to enable channel 8 to provide to its output line 16 uncontaminated digital seismic data. The novel noise suppression system, generally designated as 20, is especially adapted to remove anticipated and unanticipated, continuously-changing, multi-frequency noise signals which are contaminating the seismic signal components arriving on wires 5 and 6, while they are being gathered by channel 8 during seismic exploration, without at the same time introducing substantial distortions in the phase, frequency, and/or amplitude characteristics into the uncontaminated seismic signal on output line 16, and without requiring time-consuming manual adjustments.

System 20 broadly comprises a noise pickup detector 21 which monitors the contaminating ambient noise and feeds it to a noise discriminator 22 whose output noise data is processed by a reference noise generator 40 to produce a reference noise signal which is supplied to a digital data processor 23 within a feedback loop 26 which includes a digital filter 24, a noise simulation network 25, and a cross-correlator 42.

Feedback loop 26 interacts between channel 8 and processor 23 and provides to a second input 27 of IFP amplifier 12 a noise-cancelling error signal on line 28 having the required frequency, amplitude and phase to effectively suppress the noise signal present on the seismic data applied to the first input 13. Amplifier 12 constitutes a summing network 29.

Digital filter 24 has weights or coefficients, herein sometimes also called "parameters", which are being updated continuously by the output on line 53 derived from cross-correlator 42 which cross-correlates the substantially uncontaminated digital seismic signal on output line 16 with the simulated digital noise data supplied to line 55 by noise simulator 25. In this
manner, the coefficients of digital filter 24 are continuously being adjusted to correspond to the changes which take place in the amplitude and phase of the contaminating noise signal present in the seismic data arriving to input 13 of summing network 29.

Cross-correlator 42 uses and adaptive algorithm based on the least-mean-square technique for calculating the coefficients used by digital filter 24 in order to properly filter the digital noise data produced by noise simulator 25 and to provide an error signal to line 43 which is converted to analog form by digital-to-analog converter 70 on its output line 28. The analog error signal when applied to input 27 has the correct frequency, amplitude and phase that are required by summation network 29 for substantially complete suppression of the noise signal that is contaminating the seismic signal component at its input 13. In this manner, feedback loop 26 continuously ensures that the noise signal remains suppressed at the output line 16 even when the ambient noise signal changes with time.

**Detailed Description of the Suppression System**

Pick up detector 21 continuously monitors noise changes occurring within seismic cable 7. For this purpose there is provided across wires 5 and 6 a pair of resistors 18 having a junction 17 therebetween. The common mode electric noise signal is derived by wire 31 which has one end connected to junction 17. The magnetic noise signal is sensed by a coil 32 having one end connected to ground. The opposite ends of wire 31 and of coil 32 are connected through switches 33 and 34, respectively, to the input 35 of a noise discriminator 22. An electronic switch-select network 30 operates switches 33, 34 either simultaneously or consecutively as required to provide maximum noise pickup to input 35 of preamplifier 36. The amplified noise from amplifier 36 is filtered by a band-pass-filter (BPF) 37 which is designed
to pass the dominant frequency of the periodic noise component. In the U.S.A., the dominant contaminating noise signal has a frequency which typically is the electric power grid frequency of 60 Hz and/or its harmonics and subharmonics.

The analog filtered noise signal from BPF 37 is applied to a wave shaper 38 which supplies to the output line 39 of discriminator 22 noise data in digital form. Line 39 is connected to the input 41 of a reference noise generator 40 whose output 54 receives a reference noise signal that is applied to simulator 25 which generates a replica of the digital reference noise frequency or frequencies that will be filtered by digital filter 24.

Reference noise generator 40 includes a period counter 44 (Fig. 2) which measures the period of the dominant noise frequency to be suppressed, say the period of the 60 Hz signal.

The algorithm used by period counter 44 for calculating a running average of the period of the 60 Hz sine wave is:

\[ A_{n+1} = A_n + (P - A_n) / T_c \]

Where:

\( P \) = 60 Hz period measurement,

\( A_n \) = running average at time \( n \),

\( A_{n+1} \) = running average at time \( n+1 \), and

\( T_c \) = running average scale value.

A timing-and-control circuit 45 synchronizes the 60 Hz signal with a 1MHz clock and generates timing signals at each rising edge of the 60 Hz signal.
The period of the noise signal is measured by counting cycles of the 1MHz clock between the rising edges of the 60 Hz signal. This is accomplished with a simple 16-bit counter chain 46 formed from four 4-bit counters. On each rising edge, counter chain 46 is loaded with all zeros. It then counts 1 MHz cycles until the next rising edge occurs, at which time the accumulated count is fed into a running average filter 47 whose first stage (Fig. 2) is a 16-bit binary adder 48 consisting of four 4-bit adders which perform the calculation \((P-A_n)\).

The second stage 49 of running average filter 47 is a 24-bit binary adder consisting of six 4-bit adders. The output from average filter 47 is \(A_n + (P-A_n)/T_c\) which is \(A_n + 1\).

Filter 47 is a running averager filter (1-pole R-C type response) which is used to smooth out the output period samples from period counter 46 and to compute a very accurate digital number which represents the period. To simplify the implementation, \(1/T_c\) is restricted to powers of 2 which permits the multiplication \(1/T_c\) by means of a simple bit-shift. This is implemented by offsetting \(A_n\) and adding \((P-A_n)/T_c\).

Register 51 performs the necessary storage to produce the desired output \(A_n\) which is applied to a conversion PROM 52 consisting of two 256K EPROMS. PROM 52 converts the measured period number to a frequency number which is the frequency of the selected dominant noise frequency, say 60 Hz.

PROM 52 performs the period-to-frequency conversion according to the equation:

\[ F = K/A_n \]

Where:

\[ K = \text{scale factor as required}, \]
F = scaled frequency number of the averaged 60 Hz frequency.

The scaled frequency number F on line 54 is then passed to a CPU interface 50 within the digital data processor 23 to address the noise simulator 25 which consists of a sine-wave look-up PROM which is addressed according to the following calculation:

\[ A^{j+1} = A^j + F, \text{ where} \]

\[ A^{j+1} \] is the new address being calculated. It must be rolled around if it exceeds the address space of PROM 25.

\[ A^j \] is the address from the previous cycle.

F is the step size frequency number generated by conversion PROM 52.

The scaled frequency number can be selectively divided or multiplied by a constant to obtain the frequency numbers of harmonics or subharmonics of the fundamental 60 Hz noise signal.

Since this calculation is done at very regular intervals, a constant F will produce a constant frequency number.

The sine-wave look-up PROM 25 is a 8Kx16 bank of read-only memory. Its function is to store the digitized samples of a simulated sine wave required by the algorithm used by cross-correlator 42. Digital filter 24 receives and filters the digital noise data produced by PROM 25.

PROM 25 contains a full period (360°) of the sine wave, which, when addressed properly (i.e., with constant size steps), will generate to a data bus 56 digital data samples of the simulated sine wave having the scaled
digital frequency numbers, which may be the fundamental frequency and/or one or more harmonics or subharmonics thereof.

While the noise picked up by detector 21 is being processed by noise discriminator 22, the output seismic signal data on output line 16 of channel 8 is being clocked into an input register 60 at the seismic sampling rate. It is then read into a random access memory (RAM) 61 via data bus 56 and stored for later processing.

RAM 61 is a 2Rx16 bank of read/write memory and is used to store input data, intermediate computation products, filter weights, filter time constants, output samples, and any other dynamically changing data required by the algorithm of cross-correlator 42 and by digital filter 24.

Digital filter 24 is preferably a finite-impulse-response (FIR) filter, well known in the art, because it has desirable characteristics such as stability and linear phase response which lend themselves to well behaved implementation.

Other known digital filters, such as infinite-impulse-response (IIR) or lattice type filters could be also used in place of the FIR filter. The equations for coefficient calculation and digital filtering would necessarily be different, but the principal of operation would remain substantially the same. This invention is therefore not limited to a particular type of digital filter.

Memory addresses which have been calculated by a multiplier and accumulator (MAC) 63 are clocked into a memory address register 64 (MAR) for subsequent use. MAC 63 performs all arithmetic functions required by the cross-correlator's algorithm and by digital filter 24.

A memory address multiplexer (MAM) 65 selects the source of the memory address. This can be either from register 64 or directly from a control bus 66.
The output samples calculated by digital filter 24 are clocked into an output register (OR) 67 until needed by the digital-to-analog converter (DAC) 70 which converts the filtered digital noise data samples into an analog feedback error signal on line 28.

Sequencing-and-control network 71 generates all clocks, enables memory addresses, and provides other timing and control signals required for proper operation of digital processor 23.

The FIR equation is performed in digital filter 24 as follows:

$$\text{CORR}^j = \sum_{i=1}^{N} \text{REF}_i^j \times W_i^j$$

where

- \text{CORR}^j = \text{digital cancellation word at time step } j,
- \text{REF}_i^j = \text{the } i^{\text{th}} \text{ value of the monitored frequency at time step } j,
- W_i^j = \text{the } i^{\text{th}} \text{ filter weight at time step } j,
- N = \text{filter length},
- j = \text{time step number}, \text{ and }
- i = \text{weight counter}.

The weight update calculation is performed in cross-correlator 42, as follows:

$$W_i^{j+1} = W_i^j + 2u_{ac} \times \text{SIG}^j \times \text{REF}_i^j \text{ for } i=1,2,3...N,$$

where:

- \text{N} = \text{# of weights},
\[ u_{ac} = \text{weight time constant}, \]
\[ j = \text{time step number}, \]
\[ i = \text{weight counter}, \text{and} \]
\[ \text{SIG}_j = \text{the value of digital sample at time step } j, \]
\[ \text{and} \]
\[ w_{i}^{j+1} = \text{the } i^{th} \text{ filter coefficient at time step } j+1. \]

These calculations are performed for each noise frequency selected to become suppressed within channel 8.

The calculations are performed under the guidance of sequencing-and-control network 71. Data is taken from the appropriate memory 61, mathematically manipulated in MAC 63, and sent back to memory, or to the output of MAC63, as the filtered digital noise data, which subsequently becomes converted to analog form by DAC 70 as the analog feedback error signal on output line 28.

The noise generator 40 automatically and in near real time adjusts and updates the noise frequencies selected to become suppressed as they change with ambient noise in the environment. In turn, digital filter 24 updates the frequency, amplitude and phase of its output error signal.

The coefficients of digital filter 24 are calculated by cross-correlator 42 so as to maximally cancel the selected noise frequencies from the contaminated seismic signal arriving to input 13 of IFP amplifier 12 in channel 8. Using the digital feedback technique of the invention, the noise component signal can be attenuated by 60 dB or more.

The operational variables can be easily adjusted from a central location via CPU Interface 50 which offers the path by which digital filter 24 receives its operational
parameters, such as the noise rejection frequency or frequencies to be suppressed, the time-constants for each frequency, the speed of convergence of feedback loop 26, and other constants required for proper operation.

In sum, feedback loop 26 has one input 13 for receiving the contaminated seismic signal, and a second input 27 for receiving the error feedback signal. The error signal is available for algebraic addition in near real time because it is obtained on the basis of data previously sampled.

These two inputs at 13 and 27 are algebraically summed and the difference is amplified by IFP amplifier 12, digitized by analog-to-digital converter 14, filtered by offset filter 15 whose output seismic data on line 16 is cross-correlated with the output noise samples from noise simulator 25 by cross-correlator 42. Digital filter 24 receives its updated coefficients from cross-correlator 42. Filter 24 filters the output noise samples from noise simulator 25, and provides a digital error feedback signal to DAC 70.

The algebraic summation is accomplished preferably prior to IFP amplifier 12 to obtain optimum signal-to-noise enhancement. If desired, the cancellation could be done digitally past converter 14 within channel 8, and such cancellation would be very useful to presently used seismic data acquisition systems. On the other hand, the summation can be effected at any point within channel 8 from its input up to the output of IFP amplifier 12. In sum, the feedback error signal can be in digital form or in analog form prior to the summation, which can be carried out within the analog or digital sections of channel 8.

The accomplished summation substantially and continuously removes the noise signal from the contaminated seismic signal because the error signal is being continuously updated to take account of the changes
which occur in the frequency, amplitude, and/or phase of the noise signal being picked up by detector 21.

The present invention has been observed to suppress 60 Hz and multiple harmonics of 60 Hz noise contained within the contaminated seismic signal with 60 dB or more of noise reduction. Seismic signal distortion was minimized by limiting the suppression bandwidth to less than 3 Hz.

While the invention has been illustrated with reference to a single seismic data acquisition channel 8, it will be understood that ordinarily many such channels are employed in the field. The manner of adapting the present invention for a multi-channel acquisition system using time-sharing and multiplexing techniques is well known in the art. This invention is therefore not limited to any particular number of seismic channels.
WHAT IS CLAIMED IS:

1. A system for suppressing the effect of an ambient noise signal that is contaminating a seismic signal being gathered within a seismic channel thereby enabling said channel to produce a substantially uncontaminated seismic signal, comprising:
   a noise detector for monitoring said contaminating noise signal;
   a noise discriminator for processing the monitored noise signal into noise data;
   a reference noise generator for waveshaping said noise data into a reference noise signal;
   a signal modifier having adjustable parameters for changing said reference noise signal into an error signal having characteristics which enable said error signal to remove said noise signal from said contaminated seismic signal; and
   a signal comparator for comparing said reference noise signal with said uncontaminated seismic signal and for modifying said parameters so as to enable said signal modifier to produce said error signal.

2. The system of claim 1, wherein said channel has circuit means for subtracting said error signal from said contaminated seismic signal to thereby produce said uncontaminated seismic signal.

3. The system of claim 1, wherein said reference noise signal has a frequency which corresponds to the frequency of said monitored noise signal;
   said signal comparator is a cross-correlator; and
   said signal modifier is a digital filter having coefficients which are determined by said cross-correlator.
4. The system of claim 3, wherein
   said circuit means is an
   instantaneous-floating-point amplifier; and
   a digital-to-analog converter for converting
   said error signal into analog form.

5. The system of claim 3, wherein
   said digital filter is a FIR type digital
   filter; and
   said cross-correlator uses an adaptive algorithm
   based on the least-mean-square technique for calculating
   the filter coefficients used by said digital filter.

6. The system of claim 5, wherein
   said reference noise generator includes means
   for calculating the frequency of said noise data; and
   a multiplier for multiplying said frequency by a
   constant to obtain the frequency corresponding to a
   harmonic of said calculated frequency.

7. The system of claim 6, wherein
   said reference noise generator automatically
   adjusts said reference noise signal in accordance with
   changes in said monitored noise signal.
8. A method for suppressing the effect of an ambient noise signal that is contaminating a seismic signal being gathered within a seismic channel thereby enabling said channel to produce a substantially uncontaminated seismic signal, comprising:

monitoring said contaminating noise signal;
processing said monitored noise signal into noise data;
waveshaping said noise data into a reference noise signal;
changing said reference noise signal into an error signal having characteristics which are required to remove said noise signal from said contaminated seismic signal; and

comparing said reference noise signal with said uncontaminated seismic signal and modifying said error signal in accordance with the results of said comparison.

9. The method of claim 8, including

feeding back to said channel said error signal to thereby remove said noise signal from said contaminated seismic signal.
10. A noise suppression system, comprising:
   a noise pickup detector for monitoring the ambient noise signal that is contaminating a seismic signal being gathered within a seismic channel;
   a noise discriminator for processing said monitored noise signal into noise data;
   a reference noise generator for converting said noise data into a reference noise signal having a frequency which corresponds to the frequency or frequencies of said monitored noise signal, said noise generator automatically and continuously adjusting said reference noise signal to correspond to changes which occur in said monitored noise signal;
   a digital filter having adjustable coefficients for filtering said reference noise signal into an error signal having the required amplitude, frequency, and/or phase to remove said contaminating noise signal from said contaminated seismic signal and to enable said seismic channel to produce an uncontaminated seismic signal; and
   a cross-correlator continuously cross-correlating said uncontaminated seismic signal with said reference noise signal to modify said coefficients thereby to enable said digital filter to produce said error signal.
11. A system for suppressing the ambient noise signal which contaminates a desired signal, comprising:
   a noise pickup detector for detecting the ambient noise signal;
   a noise discriminator for processing the detected noise signal into noise data;
   a reference noise generator for converting the noise data into a reference noise signal;
   a filter for filtering the reference noise signal into an error signal which is adapted to remove the noise signal from the contaminated desired signal; and
   a cross-correlator for cross-correlating the contaminated signal with the reference noise signal and for adjusting the filter to produce the required error signal.
INTERNATIONAL SEARCH REPORT

International Application No PCT/US 87/00307

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols applicable, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC: G 01 V 1/36

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System | Classification Symbols
IPC | G 01 V

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

III. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of Document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to Claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US, A, 4527261 (M.A. SMITHER) 2 July 1985 see abstract; column 2, line 62 - column 3, line 29; column 4, lines 8-29; claims 1,11; figure 1</td>
<td>1,3,8,10, 11</td>
</tr>
<tr>
<td>Y</td>
<td>--</td>
<td>2,9</td>
</tr>
<tr>
<td>Y</td>
<td>US, A, 3704444 (A.N. SCHMIDT) 28 November 1972 see abstract; column 2, line 31 - column 3, line 5</td>
<td>2,9</td>
</tr>
<tr>
<td>A</td>
<td>Oil &amp; Gas Journal, volume 80, no. 20, May 1982, (Tulsa, Oklahoma, US), T.A. Khan: &quot;Adaptive control application in geophysical prospecting for oil&quot;, pages 125-130 see page 128, column 3, lines 15-57; figure 3</td>
<td>1,8,10</td>
</tr>
<tr>
<td>A</td>
<td>US, A, 2733412 (W.A. ALEXANDER et al.) 31 January 1956</td>
<td>--</td>
</tr>
</tbody>
</table>

* Special categories of cited documents:
  - "A" document defining the general state of the art which is not considered to be of particular relevance
  - "E" earlier document but published on or after the international filing date
  - "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  - "O" document referring to an oral disclosure, use, exhibition or other means
  - "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"Z" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search: 22nd June 1987
Date of Mailing of this International Search Report: 20 JUL 1987

International Searching Authority: EUROPEAN PATENT OFFICE

Signature of Authorized Officer: [Signature]
ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/US 87/00307 (SA 16408)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 02/07/87.

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GB-A,B 2107559</td>
<td>27/04/83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NL-A- 8203847</td>
<td>02/05/83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA-A- 1180434</td>
<td>01/01/85</td>
</tr>
<tr>
<td>US-A- 3704444</td>
<td>28/11/72</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>US-A- 2733412</td>
<td></td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

For more details about this annex:
see Official Journal of the European Patent Office, No. 12/82