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NOISE REDUCTION AND CANCELING STATIONARY SINUSOIDAL NOISE IN SEISMIC DATA ACQUISITION IN ATALA PROSPECT OF RIVER STATE.

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ABSTRACT

The process of Noise Reduction in Seismic method of prospecting have brought about improvement in data quality as well as operational efficiency. For this research two primary approaches were used for reducing seismic noise to enhance desired reflections. The first is based on recording arrangement that will cancel the unwanted signals before they are recorded in the field while the other is to process the data after they are recorded by appropriate filtering.

Noise from the Company's (United Geophysical) plant was used to generate stationary sinusoidal noise. The seismic monitor was highly contaminated with sinusoidal noise. When this noise is large compared to seismic signals, it adversely affects prestack seismic processing and subsequent interpretation.

A digital least-square filtering algorithm for cancelling stationary sinusoidal noise in seismic data was developed. The method effectively cancels sinusoidal noise in the semi data leaving the signal.

1.0 INTRODUCTION

Noise is propagated in form of waves. It is an unwanted signals, a disturbance which does represent any part of a message from a specified source. It could sometimes be described as energy which is random. It is a seismic energy which is not resolvable as primary reflections. In this sense noise includes microseisms, shot-generated noise, multiples, tape modulation noise, harmonic distortions etc. It is sometimes divided into coherent noise and random noise such as wind noise, instrument noise, and all other energy which is non-coherent while ambient seismic noise refers to the background of random earth movements.

The development in new energy sources and new field techniques in reflection recording has been the necessity for eliminating or suppressing spurious seismic signal from ground motion not associated with reflections. A lot of these spurious ground disturbance can be removed by proper recording and data processing procedures. These process of Noise reduction in seismic method of prospecting have brought about improvement in data quality as well as operational efficiency.

In seismic data acquisition, power-line interference corrupts the seismic recording with 60Hz sinusoidal noise and higher harmonics (Linville and Meek, 1992). Rotating machinery can also create this type of interference. In the marine case, this type of noise may arise from on-board generators. When sinusoidal noise is large compared to seismic signals, it adversely affects prestack seismic processing and subsequent interpretation.

There are two primary approaches used for cancelling seismic noise to enhance desired reflections. One is to set up a recording arrangement that will cancel the unwanted signals before they are recorded in the field. The other is to process the data after they are recorded in a way that will suppress the nose, generally by appropriate filtering. In Harris et al (1991), a noise cancelling method using a Widrow adaptive filter was used to attenuate power plant interference from micro-earthquake recording. Geophones were placed around the source of the noise and then adaptively subtracted during processing. There are several ways of removing sinusoidal interference during processing. Spike deconvolution can be applied to the line interference. A digital notch filter can be applied. These have the tendency to attenuate signal frequencies around the line frequency. In Hu and Massel (1991), harmonic interference was removed in a vertical seismic profile (VSP) by subtracting noise amplitude spectra.

A way of improving the signal to Noise ratio (S/N) is to utilize artificial electromagnetic (EM) fields as done in frequency and transient EM sounding methods (Nekut and Spies, 1989). Under the assumption that instrument noise of modern equipment is small, the main problem with electromagnetic methods are broad band artificial noise due to power lines, generators, railroad grids etc, natural noise such as spheric (caused by thunderstorm activity, etc) and wind noise (Macnae et al, 1984). S/N ratio can be generally improved in three ways:

(i) Through survey design with the choice of appropriate transmitter and receiver locations, the choice of acquisition procedure (such as the number of single records acquired for stacking), and the choice of the stacking technique (Strack et al, 1989).

(ii) In very noisy environments the noise can be reduced by analog filters implemented in the acquisition system, and the signal can be increased by increasing the transmitter moment.

(iii) After data acquisition the S/N ratio can be improved by digital data processing techniques.

It has been reported by Nyman and Gaiser (1983) that, in the United States, the high line frequency rarely deviates from 60Hz by more than 0.03Hz. Other types of noise such as generators and pump noise are also stationary over recordings of a few seconds in length. Optimal filters such as Widrow adaptive filters, used for noise that is non-stationery have the tendency to withdraw noise from the line frequency and attenuate signal. The Wiener least-squares (Linville and Meek, 1992) filter used in this algorithm will not do this if it is designed over a portion of the trace where the nose is large.

2.0 LOCATION

The Trans-Atala 3-D prospect spans a large area of OMLS (Omission Lines) 35 and 46.

The total surface area of the prospect is approximately 256 square kilometres. The area is swampy and low-lying, with surface elevation gradually rising from 2.28m in the south to 1.98m up north. Vegetation varies from Mangrove to Rain forest inter-spersed with raffia palms. The area is drained by numerous rivers and creeks which makes access to some locations difficult.

The prospect covers Burugbene and Ogbotobo fields. The adjoining communities are Ekurugbene, Bassan, Lobia, Vampire, Eremor, Amabilou etc. These are all in Western Ijaw Local Government Area of River State.

3.0 THEORETICAL ANALYSIS

3.1 GEOPHONE ARRAY

The directional response of any linear array is governed by the relationship between the apparent wavelength λ_a of a wave in the direction of the array; the number of elements n in the array and their spacing ΔX. The response is given by a response function, R given by

$$R = \frac{\text{Sin } n\beta}{\text{Sin } \beta}$$

$$\text{where } \beta = \frac{\pi \Delta X}{\lambda_a}$$

R is a periodic function that is fully defined in the interval $0 \leq \Delta X \leq 1$ and is symmetrical about $\Delta X/\lambda_a = 0.5$. Typical array response curves are shown in fig.1. Arrays comprising areal rather than linear patterns of phones may be used to suppress horizontal noise travelling along different azimuths.

3.2 OPTIMUM WIENER FILTER

The basic design of this noise-cancelling algorithm is shown in fig.2. A reference sinusoidal trace and a corrupted data trace were used to design an Optimum Wiener Filter. The Wiener Filter is then used to adjust the amplitude and phase of the sinusoidal trace with the sinusoidal noise in the data trace. The reference sinusoidal trace is then subtracted from the data trace removing the sinusoidal noise. The algorithm hinges around the Wiener filter design.

Levinson (1947) developed a fast recursive algorithm to solve the normal equations for a Wiener Optimum filter which is referred to as the Wiener-Levinson algorithm.

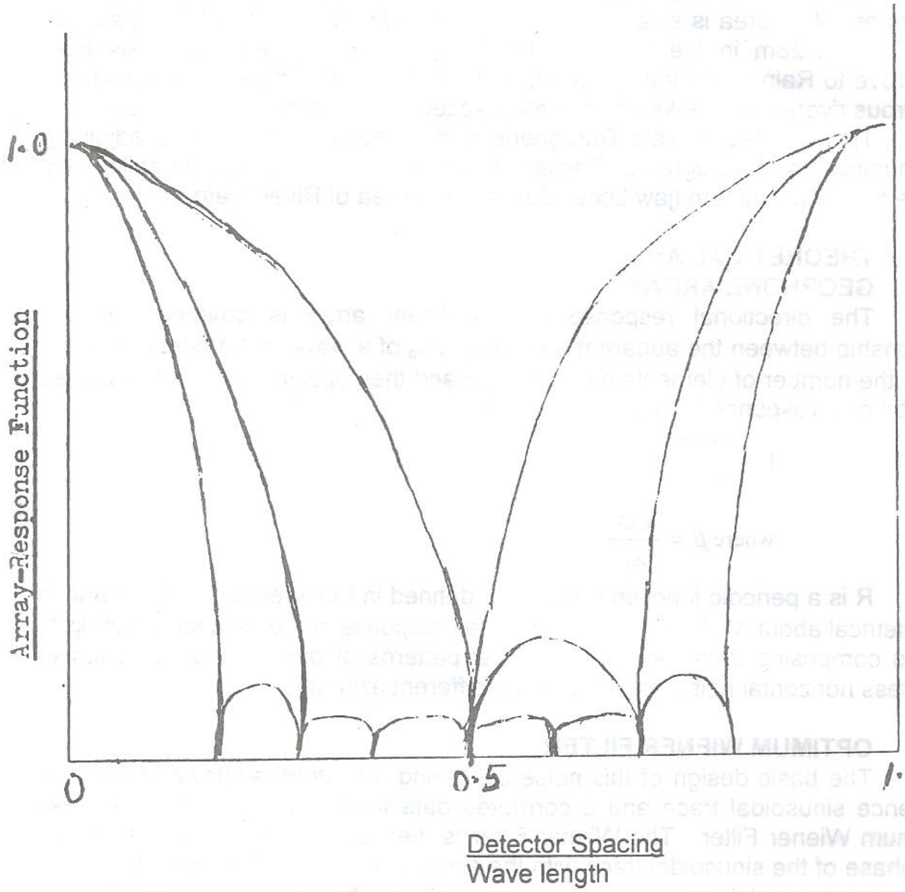

Fig. 1: Response function for different detector Arrays (Al – Sadi, 1980).

OPTIMUM WIENER FILTER

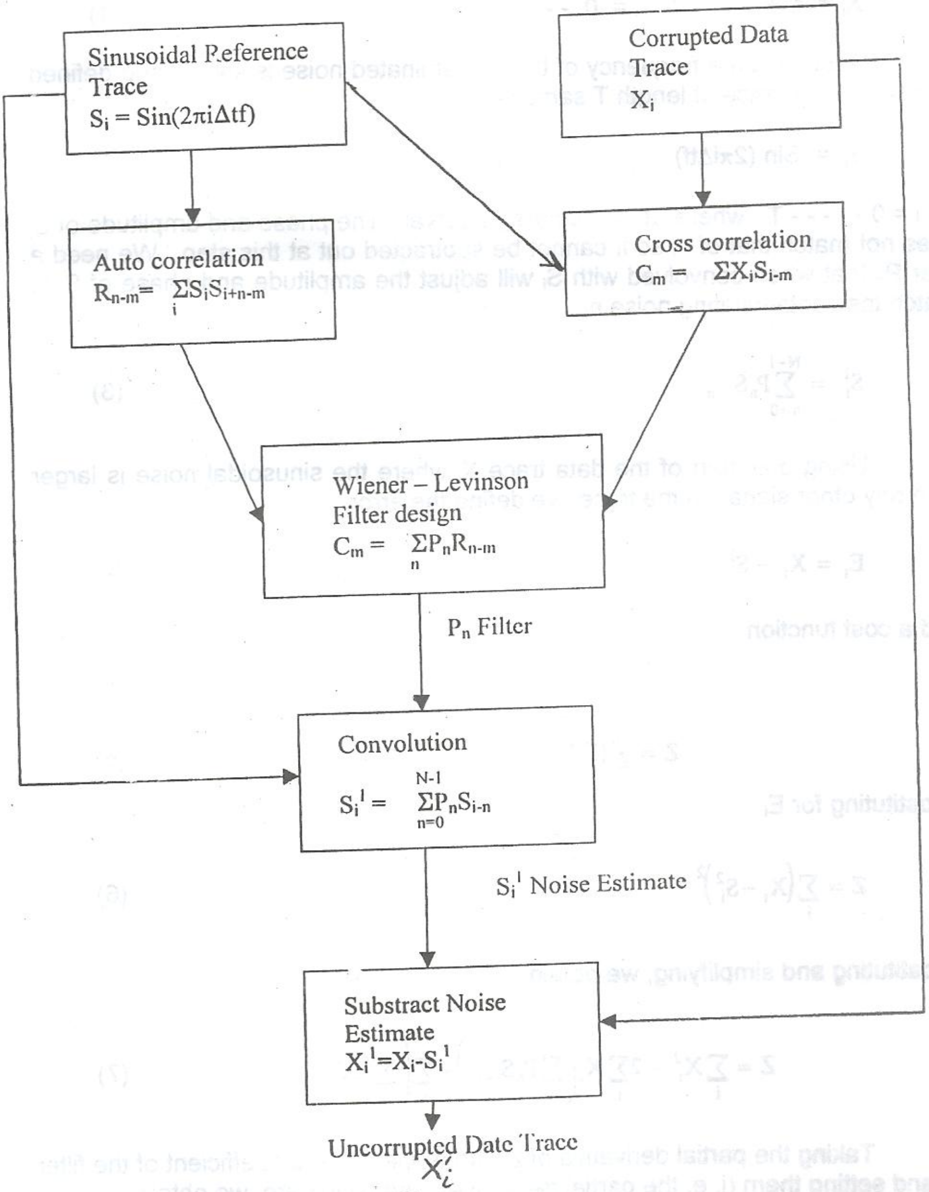

Fig.2: Wiener – Levinson filter

In the application, assuming the data trace X_i comprises a signal, r_i and sinusoidal noise n_i

$$X_i = r_i + n_i \qquad \text{for } i = 0 \text{ - - - - - } T \tag{1}$$

Assuming the frequency of the contaminated noise is known and defined as a sinusoidal trace of length T samples.

$$S_i = \text{Sin}\,(2\pi i \Delta t f) \tag{2}$$

for i = 0 - - - - - T where Δt = sampling interval. The phase and amplitude of S_i does not match that of n_i so it cannot be subtracted out at this step. We need a filter P_n that when convolved with S_i will adjust the amplitude and phase of S_i to match the contaminating noise n_i.

$$S_i^1 = \sum_{n=0}^{N-1} P_n S_{i-n} \tag{3}$$

Using only part of the data trace X_i where the sinusoidal noise is larger than any other signal on the trace, we define the error

$$E_i = X_i - S_i^1 \tag{4}$$

and a cost function

$$Z = \sum (E_i)^2 \tag{5}$$

Substituting for E_i

$$Z = \sum_i \left(X_i - S_i^2\right)^2 \tag{6}$$

Substituting and simplifying, we obtain

$$Z = \sum_i X_i^2 - 2\sum_i X_i \left(\sum_n P_n S_{i-n}\right) + \sum_i \left(\sum_n P_n S_{i-n}\right)^2 \tag{7}$$

Taking the partial derivative of Z with respect to the coefficient of the filter P_n and setting them (i. e. the partial derivatives) equal to zero, we obtain

$$\frac{\partial Z}{\partial P_m} = -2\sum_i X_i S_{i-m} + 2\sum_i \left(\sum_n P_n S_{i-n} \right) S_{i-m} = 0 \qquad (8)$$

Therefore

$$\sum_i X_i S_{i-m} = \sum_n P_n \sum_i S_i S_{i+n-m} = 0 \qquad (9)$$

The first summation in the above equation is the cross correlation C_m of the corrupted data trace X_i with the sinusoidal reference trace S_i as shown in equation (1) and fig. 2 . The second summation is the auto correlation R_{n-m} of the sinusoidal reference trace convolved with the filter. This is the basic principle upon which the filter process can be achieved. The cross correlation and auto-correlation are shown in Fig. 2

Equation 9 in the normal equation used in Wiener single – channel filter design and can be solved rapidly using Levinson's recursion algorithm.

The number of lags required in the cross correlation function to ensure that the filter will be designed on the correlation maximum is a function of the frequency of the sinusoid. As a result of the cyclic nature of the sinusoid, cross – correlation with a data trace will produce a cyclic function. Therefore cross correlation lags spanning two periods of the sinusoid are all that are required to ensure that the correlation maximum will be available for filter design. The number of the lags, L used is given by

$$L = \frac{2}{f\Delta t}$$

It should be noted that there will be more corosscorrelation lags M computed than are needed for filter design, i.e. M >> N, because it is not known a priori which N – point set of cross correlation lags will produce the Wiener filter having the least prediction error among all possible N – point sets of lags (Linville and Meek, 1992). The filter length N corresponds to the number of auto correlation lags required. A short filter length of three, five, or seven points is normally used. From synthetic tests we found that the prediction error for a three point filter is 54dB down and for seven points is 60dB down form the peak sinusoid amplitude.

METHODOLOGY/FIELD EXAMPLE

The linear array of geophones was adopted for this research. It was carried out close to the company's power plant. Here the application of seismic theory is considered to the design of equipment for generating seismic pulses, and detecting and recording the earth's response to the passage of seismic waves through it.

In recording ground motion from reflected seismic waves it is customary to receive the signals from each shot point. Dynamites are detonated from the shot point with a large number of geophones and the data obtained were highly contaminated with 60Hz line interference. Reflectors at late record times are totally obscured by the line noise. The Macromax was used to carry out the processing in the field with the basic design of noise-cancelling algorithm shown in Fig. 2.

In this method, we assume the noise comprises a stationary sinusoid of a single frequency. An analytic sinusoidal trace was generated at the frequency of the interferring noise. A short Wiener least-squares filter is then used to match the amplitude and the phase of the sinusoidal with the stationary sinusoidal noise in the data trace. The sinusoid is then subtracted from the corrupted data trace leaving the signal.

4.0 DATA ANALYSIS AND DISCUSSION

The Macromax is used for the analysis of the data. The Wiener-Levinson filter adjusts the amplitude and phase of the sinusoidal reference trace to match the sinusoidal noise in the corrupted data trace. The noise estimate is then subtracted from the corrupted data trace. The frequency of the sinusoidal reference trace can be automatically derived by spectra analysis of the recorded data.

A synthetic seismogram was generated to demonstrate the necessity for cancelling sinusoidal noise early in the processing sequence. The field data is shown in Fig. 3 by convolving a broadband minimum phase wavelet with a white reflectivity sequence. Eight sinusoids of differing frequencies, amplitudes and initial phases were added to each trace of the signal to produce corrupted data record.

The source of field example was the dynamite, and the 192 trace record is highly contaminated with line interference at 60Hz as shown in Fig. 4.

The next result is obtained by applying a notch filter. This has done a good job of removing the 60Hz line noise, however, the notch filter also removes signal frequency components near the line frequency as shown in Fig. 5.

The final stage is the result of applying the noise cancelling algorithm to cancel the 60Hz noise. A comparison with the notch filter result shows that the noise cancelling procedure has done an excellent job of cancelling the 60Hz sinusoidal noise yielding a noise-free signal spectrum without attenuating signal frequency components near the line frequency. Fig. 6 shows the results of applying the noise cancelling algorithm to cancel the 60Hz noise..

CONCLUSION

A digital least-squares filtering algorithm for cancelling stationary sinusoidal noise in seismic data was carried out in Atala prospect of River State. The algorithm provided excellent sinusoidal noise cancelling when the noise is stationary. It differs from the usual notch-filtering techniques because the sinusoidal noise is cancelled without attenuating signal frequency components near the line frequency.

In the linear array of geophones, noise was almost completely suppressed but not as much as the digital least-squares filtering algorithm.

Noise reduction or cancellation will lead to spectacular improvement in data quality as well as in operational efficiency. The reduction in noise will obviously lead to better interpretation of the seismic monitor resulting in quality discovering of faults, anticlines, salt domes and reefs. Many of these are associated with the accumulation of oil and gas.

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Synthetic Seismograms

Canceling Stationary Sinusoidal Noise

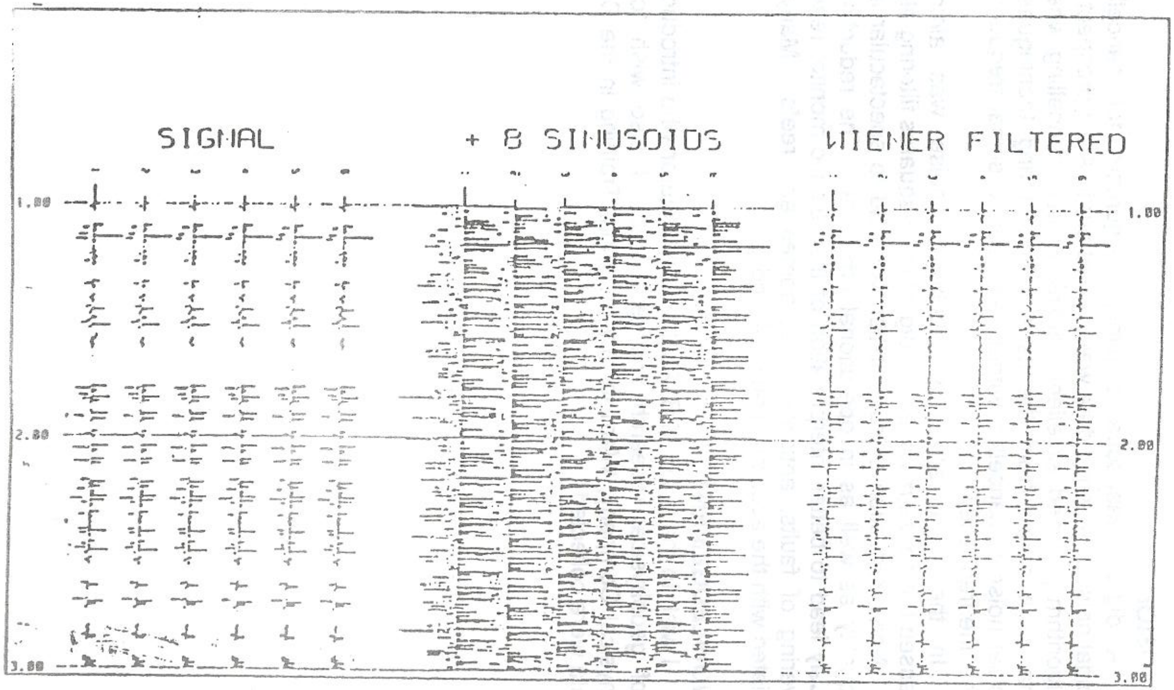

Fig 3. Synthetic Seismograms

Dynamite shot record contaminated with 60Hz line interference

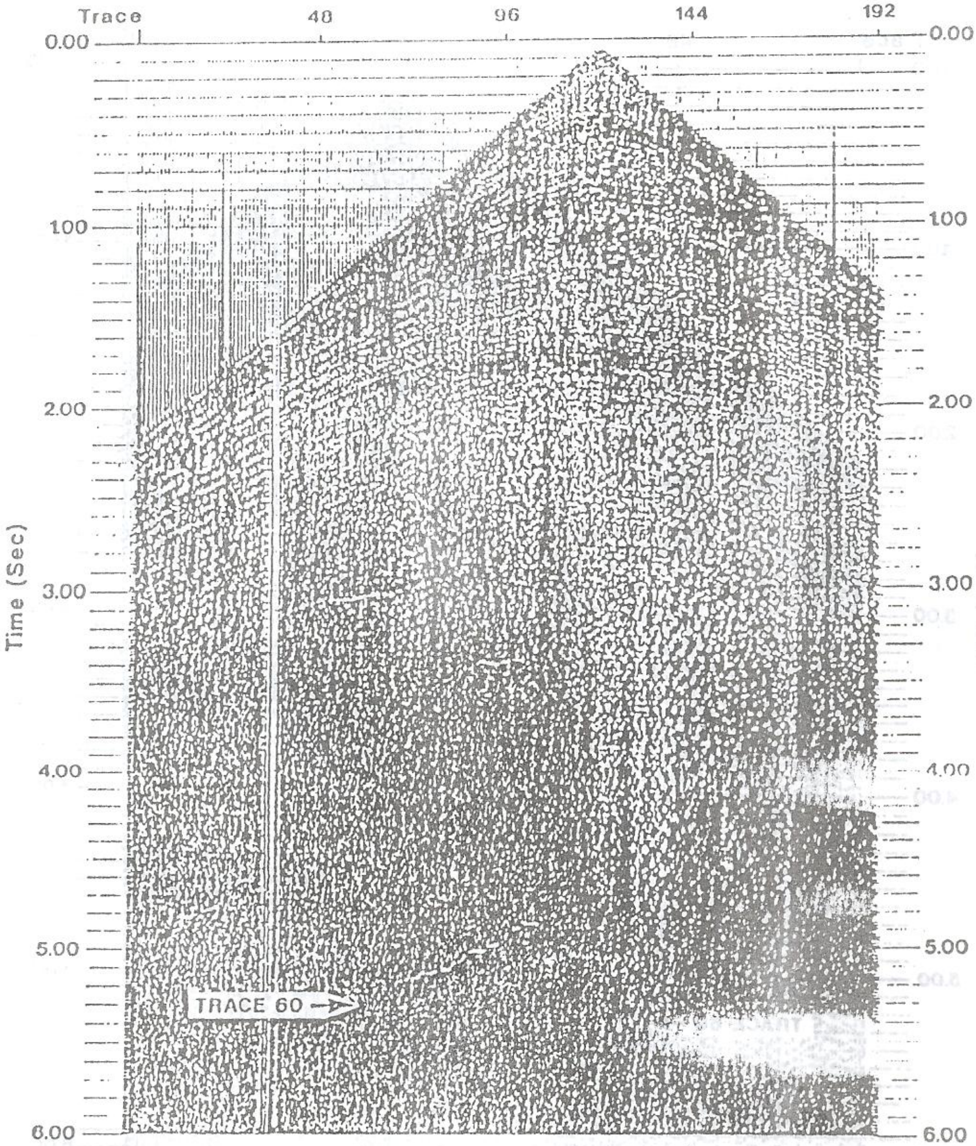

Fig 4. Dynamite shot record contaminated with $60H_z$ line interference

Application of notch filter to the field data

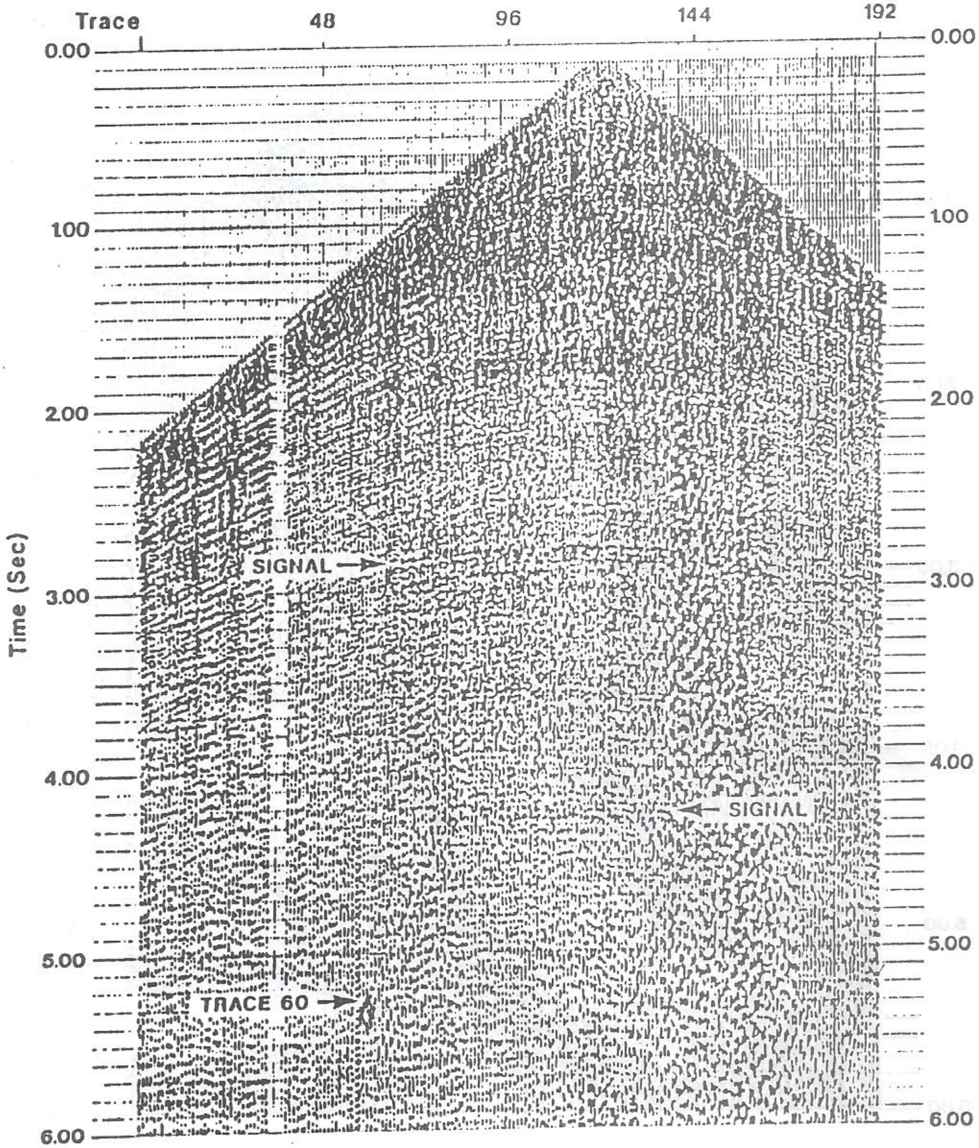

Fig 5. Application of notch filter to the field data

Noise cancelling algorithm

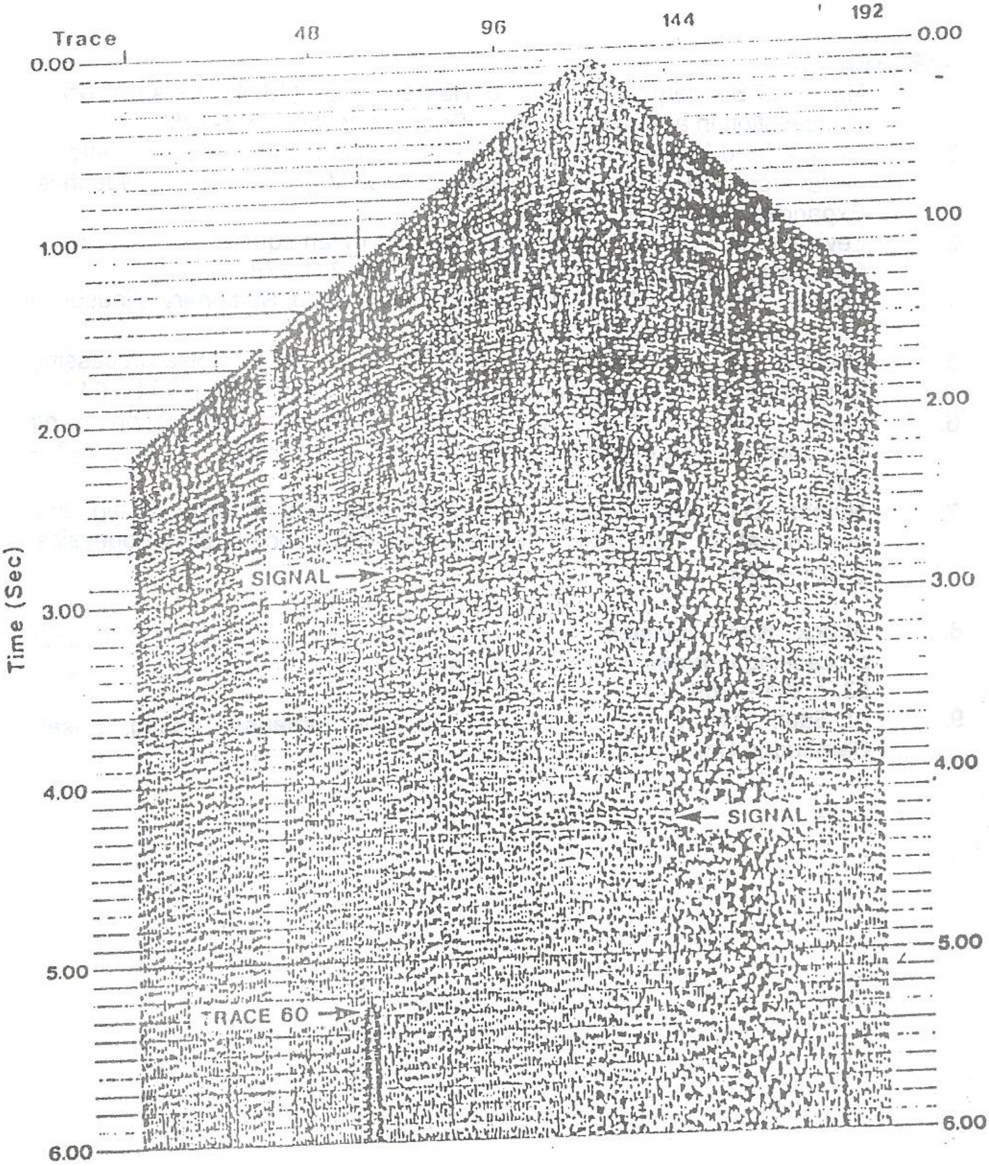

Fig 6. Noise cancelling algorithm

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