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COMPLETE SPECIFICATION

Continuously Time Varying Filtering of Seismic Records

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organized according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, 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:—

This invention relates to seismic exploration and more particularly to the optimum filtering of seismic records.

The present invention provides apparatus for time varying filtering of a seismic trace, including a first time domain filter which is optimum for filtering a seismic trace at a first record time and a second time domain filter which is optimum for filtering said trace at a later record time, and means operable to vary the weight of the output of at least one of the filters during the interval between the first and later record times in accordance with linear function of time. The invention also provides a method of continuously time varying filtering a seismic trace which comprises: applying two different time domain filters to the seismic trace wherein one time domain filter is optimum for filtering the seismic trace at a first record time and the other time domain filter is optimum for filtering the seismic trace at a later record time, and varying the weight of the output of at least one of the filters during the interval between the first and later record times in accordance with a linear function of time.

The weights of the outputs of the filters may be simultaneously varied in opposite senses as predetermined functions of the time scale of the trace. The outputs of the filters may be summed.

The present invention is particularly useful in connection with known common depth

point (CDP) seismic exploration methods, such as disclosed in U. S. Patent No. 2,732,906 to Mayne. It is also useful in enhancement and analysis of seismic traces forming seismic section displays.

In one embodiment of the invention, where a plurality of filters are uniquely related to different but adjacent data gates from a seismic trace, a first filter is applied to a given data gate from the trace with the weight of the first filter being varied from a minimum to a maximum while the weight of the output of the second filter tailored to the preceding data gate is varied from a maximum to a minimum and the weight of the output of the first filter is varied from a maximum back to a minimum while the weight of the output of the third filter tailored to the next succeeding data gate is varied from minimum to maximum. In this way continuously time varying filtering is achieved by linear interpolation between contiguous filters within a set of filters.

By way of example, the invention will be described with reference to the accompanying drawings in which:

FIGURE 1 illustrates the use of filters in accordance with the present invention;

FIGURE 2 illustrates the time variation between the filters of FIGURE 1;

FIGURE 3 illustrates a control system for imposing the time-dependent weights and filters of FIGURE 1 to a given seismic trace;

FIGURE 4 illustrates another form of the invention; and

FIGURE 5 illustrates the weights of the filters of FIGURE 4.

Section I—Introduction

The invention involves the use of a plurality of filters for each seismic trace. By way of example, each seismic trace will be divided into a plurality of time gates which may

number twenty, more or less. A time domain filter having filter points of the order of thirty points, more or less, may be tailored to provide optimum filtering for each of the twenty
 5 time gates. Preferably, the filters will be uniquely related to the signal and noise character of a given time gate. In this way, the results of an analysis of successive time gates on each seismic trace are employed
 10 where the results of each analysis are separate and distinct filters tailored to minimize, for example, unwanted noise and to accentuate desired signals from the given time gate.

Tailoring a filter in dependence upon the
 15 particular character of signal and noise components of a section of a trace may be carried out in accordance with known techniques, such as described by Schneider et al. in an article entitled "A New Data-Processing
 20 Technique for the Elimination of Ghost Arrivals on Reflection Seismograms", *Geophysics*, Vol. XXIX, October 1964, particularly at page 800 et seq. An optimum frequency domain filter is described in *An Introduction to the Theory of Random Signals and Noise*, by Davenport and Root, McGraw-Hill Book Company, Inc. (1958), particularly
 25 at page 225. Equation (11-12) describes how the desired filter can be approximated satisfactorily. A further exposition of the tailoring of filters is given in *Extrapolation, Interpolation, and Smoothing of Stationary Time Series*, by Norbert Wiener, The Technology Press (1960), in Section 2, page 131 et seq.
 30 Wiener's description is in terms of both the frequency domain and the time domain.

In filtering seismic traces in accordance with the present invention, the filters employed are time domain filters which are preferably such that phase distortion will not be
 40 introduced in the filtering operation. In accordance with the known procedure above identified for constructing filters, the seismic trace preferably will be divided into a plurality of time gates with a filter tailored to the properties of a trace for each such time gate.

Once the filters for a given trace have been constructed, then the filters are applied to the seismic trace to produce an output trace
 50 which is optimally filtered. Filtering and the compositing of the filtered trace forms the subject matter of the present invention.

Section II discloses the method and system for utilization of the filters. With an understanding of the method for construction of optimum filters such as disclosed in Section I, or when concern is solely with use of a plurality of filters simultaneously applied to a given seismic trace, then the disclosure contained in Section II may be employed in
 60 applying such filters.

Section II—Filter Operation

The filter for each data gate will be a multi-point time domain filter. The time domain

filter, in theory, may be either an analog or a digital filter of the type generally illustrated in FIGURE 1 where, for convenience, a family of seven point time domain filters has been illustrated.

In FIGURE 1, filters 11-18 are to be applied to a seismic trace as it is reproduced from a drum 20. The drum 20 is driven by a motor 21 by way of linkage 22. Motor 21 also drives a recording drum 23 by way of linkage 24.

Seven time spaced signals are applied, by way of a multi-channel switch 31, to a first set 32 of weighting resistors and thence to a summing unit 33. The output of the summing unit 33 is applied by way of an output weighting resistor 34 to a summing unit 36. The switch 31 is selectively opened and closed by a solenoid 35. In a similar manner, a multi-channel switch 41 serves to apply the signals through the set 41 of input weighting resistors to a summing unit 43 whose output in turn is applied by way of output weighting resistor 44 to the output summing unit 36. Switch 41 is actuated by solenoid 45. Multi-channel switches 51-56, selectively opened and closed by relays 61-66, respectively, apply signals from drum 20 to filters 13-18, respectively. Output weighting resistors 71-76 apply the filtered output signals to the summing unit 36.

The sets 32, 42, etc. of weighting resistors preferably are selected or adjusted to the needs of each data gate. Filter 11 will be tailored to the needs of trace 80, FIGURE 2, in the data gate centered at time T_1 . Filter 12 is particularly related to the needs of the trace in the data gate centered at time T_2 ; filter 13 to the data gate centered at time T_3 ; filter 14 to the data gate centered at time T_4 ; filter 15 to the data gate centered at time T_5 ; and filter 16 to the data gate centered at time T_6 (not shown). Additional filters (not shown) are provided, one for each of the succeeding data gates to the end of the trace.

The filters 11-18, etc. are successively and sequentially applied for and removed from operation upon the trace in an overlapping time relation. During the interval that any one filter is applied to the trace, the output weighting resistor is varied as a predetermined function of time from minimum to maximum and back to minimum such that in general at any instant there will be two filters effectively applied to a trace.

More particularly, at time T_0 , FIGURE 2, the switch 31 will be closed. From the beginning of the trace time T_0 , the switch 31 is closed and the weighting resistor 34 is bypassed by switch 41a (Fig. 3) so as to have zero attenuation to give the filter 11 a weight of "one". At time T_1 , relay 45 is actuated to close switch 41 and open switch 41a. At this instant, resistor 44 has resistance such

At the weight of the filter 12 is zero. During the interval from T_1 to T_2 , all switches 31 and 41 are closed. During this interval, the resistor 34 is actuated to change the weight of filter 11 preferably linearly from "one" to "zero". Concurrently therewith, output resistor 44 is actuated to alter the weight of the output from filter 12 from "zero" to "one".

At time T_2 , relay 35 is actuated to open switch 51. During the time interval T_2 to T_3 , resistor 44 alters the weight of the output of filter 12 preferably linearly from one to zero while resistor 71 alters the weight of the output of the filter 13 from zero to one. At time T_3 , switch 41 is open, switch 52 is closed, and so on until the entire family of filters has been applied to the trace on drum 20 with the weights of the outputs selectively varied to shift progressively along the length of the entire trace such that each data gate along the trace has had applied to it a filter of optimum character. By the application of the successive filters and the cycle weighting of the filter outputs, a smooth transition from filter to filter is provided along the entire record length.

FIGURE 2 diagrammatically illustrates the variations in the filtering operation. A seismic trace X_s is represented by the waveform 80. The weight of the output of filter 11 is represented by the portions 81 and 82. The weight of filter 12, as controlled by resistor 44, is represented by segments 83 and 84. It will thus be seen that during the interval T_1 to T_2 , the weight of filter 11 decreases linearly in accordance with the function 82 from a weight of one to a weight of zero. Concurrently, the weight of the output of filter 12 as controlled by resistor 44 increases linearly from zero to one. After time T_2 , filter 11 has no further part to play in filtering trace 80. Thus, each filter is effective for a period which is roughly equal to the length of two data gates. The data gates may be centered at uniform time intervals. In general, and as shown in FIGURE 2, the data gates may not be uniform. In FIGURE 2, the data gates have increasing length with increasing record time.

The control of the switches 31, 41 and 51—56 and the output weighting resistors 34, 44, and 71—76 is represented by the control units 100 and 101, respectively. Their operation is synchronized as represented by linkages 102 and 103, respectively, leading from shaft 22.

In FIGURE 2, the functions 81 and 82 have been plotted along line 85. The functions 83 and 84 have been separately plotted along line 86. Lines 87, 88, 89, and 90 illustrate lines along which weighting functions at later record times have been plotted. It will be noted that the intervals between the centers $T_1, T_2, \dots, T_{i-1}, T_i, T_{i+1}, \dots$ grow progressively longer. That is, the interval between T_1 and T_2 is less than any of the suc-

ceeding time intervals. The weighting functions plotted along lines 85—90 illustrate the transition from one filter to another as a function of record time.

One mode of accomplishing this transition is illustrated in FIGURE 3 wherein the same reference characters have been employed as in FIGURE 1. The drum 20 is driven by motor 21 and the linkage 102 drives an arm 100a in synchronism with movement of the drum 20 past the pickup heads 20a associated therewith.

In the position shown, the arm 100a completes a circuit from a battery 100b through both the relay coils 35 and 45. As long as both circuits are complete, both switches 31 and 41 are closed so that both the filters 11 and 12 are applied to the trace reproduced from drum 20.

The linkage 103 drives a first reducing element 101a which in turn drives a second reducing element 101b. The linkage 101c thus serves to drive the variable arms and resistances 34, 44, and 71 along with the other variable resistances cyclically from a value which effectively is an infinite resistance to zero resistance and back to infinity. For example, resistance 44 has high resistance at time T_1 , FIGURE 2. The resistance would be such that it would be decreased linearly during the interval T_1 to T_2 , FIGURE 2, and then would be increased linearly during the interval T_2 to T_3 of FIGURE 2. With such variation in resistance, the weights of the filter output vary in accordance with functions 83 and 84. As shown, the unit 101 would operate for constant spacing between the centers of data gates. Where the spacing between the centers of data gates increases with record time, the ratio between the input and output drives on linkages 103 and 101c would be varied as a function of record time.

For each cycle of the linkage 101c, the arm 100a will shift from one pair of output contacts 100c and 100d to a second pair of contacts 100d and 100c. The relay coil 35 is de-energized and the relay coil 61 is energized at time T_2 of FIGURE 2.

The foregoing description of FIGURES 1—3 involves primarily an analog system wherein the time varying seismic signals reproduced from drum 20 are applied to time domain filters 11—18 in accordance with a predetermined time schedule. The time domain filters are illustrated as being seven point filters. The filters may involve a greater number of filter points.

In some cases, it may be preferred to employ digital techniques for the performance of a filtering operation wherein the filters may be stored in the memory of a computer system and successively applied to the seismic trace as it is fed to the computer with the weighting as above described being applied to

the filter outputs. Such an operation is discussed hereinafter.

In the system illustrated in FIGURES 1 and 3, the signal from trace 80 of drum 20 is separately filtered by two filters at any given record time. The filter outputs are then modulated in accordance with the functions shown in FIGURE 2 effectively to vary the filter applied to the seismic trace.

In FIGURE 4 a modified mode of operation is illustrated wherein the seismic trace is applied only to one filter at a time and the filter character is varied during filtering of a selected interval of a seismic trace.

FIGURE 5 illustrates three seven-point time domain filters which form a basis for the system illustrated in FIGURE 4. In FIGURE 5, the function 120 represents the filter 121 of FIGURE 4. The function 122 represents the filter 123 of FIGURE 4. For the purpose of the following description, it will be assumed that the filter 121 is the filter to be applied to trace 114 from drum 115 at the time T_i and filter 123 is a different filter to be applied to trace 114 at the time T_{i+1} . Filter 125 is the filter to be applied to the trace at time T_{i+2} .

Filter 121 includes seven multipliers 131—137. Filter 123 likewise includes seven multipliers 141—147. The outputs of multipliers 131—137 are summed in unit 138 and the sum is applied by way of gate 139 to a channel 140 leading to a drum 116 on which the filtered signal is to be recorded. Similarly, the outputs from multipliers 141—147 are applied to an adder 148 and then by way of gate 149 to channel 140 leading to drum 116. The output from multiplier 131 is weighted in dependence upon a voltage from a control unit 161. Control unit 161 includes a battery 161a, connected in series with a center tapped potentiometer 161b. The variable tap 161c on unit 161 is connected to the one input of the multiplier 131. The first pickup 117a on drum 115 is connected to a second input of multiplier 131. Similarly, pickups 117b—117g are connected to the inputs of multipliers 132—137, respectively, as well as to the inputs of multipliers 141—147, respectively, and to the multipliers in filter 125. Multipliers 141—147 are controlled by units 171—177 respectively. The variable taps on units 161—167 and 171—177 are controlled by a linkage 170 operated in synchronism with the drums 115 and 116. Variation of the variable tap 161c modifies the weight of the signal from multiplier 131 linearly over the time interval from time T_i to time T_{i+1} . The variation is from a value represented by the negative element 120a of function 120 to the value of the positive ele-

ment 122a of function 122. It will be apparent that the variation is linear and may be continuous or it may be linear but in discrete steps. Similarly, the signal from trace 114 may be continuous or it may be discrete.

At time T_{i+1} , gate 139 may be closed and gate 149 may be opened, whereupon units 171—177 will effectively control the weights of multipliers 141—147 to vary the filter 123 over the interval T_{i+1} to T_{i+2} . The variation will be linear for each of the channels in dependence upon the difference between the respective elements of functions 122 and 124 which represent an incremental filter as subsequently defined herein by equations (8) and (9).

While the foregoing has been described in connection with a system primarily analog in form, it will be understood that the same operations may be carried out in connection with the programmed operation of a digital computer.

In order to assist in further understanding the operation described, the following analysis and proof have been developed and will be found to be helpful, particularly with reference to digital computer operations as contrasted with analog operations shown in FIGURES 1 and 3.

FIGURES 1—3—Analysis

In FIGURES 1—3, time varying filtering is carried out by filtering each trace twice and blending of the output with suitable weighting to accomplish the time interpolation. In general, trace X is to be time-variant filtered by the filter set described as $h_i(m\Delta t, T_i)$ where $i=1, 2, \dots, K$; h_i is one of a set of time variant filters applied to the trace; m is an input time summation index of the sample points along the trace to be filtered, and Δt is the sampling interval between successive sample points. Such filters are noted in FIGURE 2. The weighting of the filters between any pair of gate center times such as T_i and T_{i+1} is by a linear interpolation performed such that, as one filter is ramped-off, the next is ramped-on. This same net effect may be accomplished by filtering the trace X, twice with staggered sets of filters and performing a weighted stack of the output.

Each filter $h_i(m\Delta t, T_i)$ is applied full weight between gate center times T_{i-1} and T_{i+1} , therefore two different filters are applied between any two adjacent gate center times. Two 31-point filter outputs may be defined as follows:

$$y_i'(n\Delta t) = \sum_{m=-15}^{15} h_i(n\Delta t - m\Delta t, T_i) X_i(m\Delta t) \quad (1)$$

and

$$y_i^{i+1}(n\Delta t) = \sum_{m=-15}^{15} h_i(n\Delta t - m\Delta t, T_{i+1}) X_i(m\Delta t)$$

for

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$$T_i \leq n\Delta t < T_{i+1}$$

$$\Delta t = 4 \text{ msec}, \quad i = 1, 2, \dots, K-1,$$

where n is an output time summation index then be weighted and summed to give the 10
of the sample points along the filter trace. desired output $y_i(n\Delta t)$ as follows:
These two suboutputs for each time gate will

$$y_i(n\Delta t) = \left(\frac{T_{i+1} - n\Delta t}{T_{i+1} - T_i} \right) y_i'(n\Delta t) + \left(\frac{n\Delta t - T_i}{T_{i+1} - T_i} \right) y_i^{i+1}(n\Delta t) \quad (2)$$

$$T_i \leq n\Delta t < T_{i+1}$$

$$i = 1, 2, \dots, K-1.$$

- 15 In digital computer operations if the weights in Equation 2 are calculated for each output point, the capacity of the computer is greatly taxed. Preferably, therefore, the gate center times are constrained in such a manner that the weights in Equation 2 can be precalculated and stored in a table. To do this, it is required that $T_{i+1} - T_i = q \cdot 32\Delta t$ where $q=1, 2$ or 4 . That is, the gate center times may be spaced 32, 64, or 128 blocks apart. With the substitution, 25

$$n\Delta t = T_i + p\Delta t$$

and the constraint,

$$T_{i+1} - T_i = q \cdot 32\Delta t$$

the weights in Equation 2 become

$$30 \quad \left(\frac{T_{i+1} - n\Delta t}{T_{i+1} - T_i} \right) = \frac{q \cdot 32\Delta t - p\Delta t}{q \cdot 32\Delta t} = \frac{32q - p}{32q} \quad (3)$$

$$\left(\frac{n\Delta t - T_i}{T_{i+1} - T_i} \right) = \frac{p}{32q}$$

for

$$p = 0, 1, 2 \dots 31q.$$

Therefore the output $y_i(n\Delta t)$ becomes,

$$35 \quad y_i(T_i + p\Delta t) = \frac{32q - p}{32q} y_i'(T_i + p\Delta t) + \frac{p}{32q} y_i^{i+1}(T_i + p\Delta t) \quad (4)$$

for

$$p = 0, 1, 2 \dots 31q.$$

The table of weights $f(p, q) = \frac{32q - p}{32q}$ need only be determined and stored for $q=4$. The values for $q=2$ and 1 can be obtained by decimation of the basic table, for example, 40

Weight Function							
5	$f(p,q=4)=1$	127/128	126/128	125/128	124/128	123/128	etc.
	$f(p,q=2)=1$	—	63/64	—	62/64	—	etc.
	$f(p,q=1)=1$	—	—	—	31/32	—	etc.

The weight function of $\frac{p}{32p}$ is of course

just $1-f(p,q)$. For each time zone T_i , T_{i+1} the program must determine q . The logic will then automatically select the correct set of weights from the stored table. For times preceding the first gate center T_1 the first filter will be applied $h_i(m\Delta t, T_1)$, and for times

greater than the last gate center T_K the last filter will be applied $h_i(m\Delta t, T_K)$.

This computer operation will effect continuously varying filters with time.

FIGURES 4 and 5—Analysis

A filter set $h(m\Delta t, T_k) k=1, 2, \dots, N$ is to be applied in continuously varying manner. An interpolated filter between times T_i and T_{i+1} is given by equation 5:

$$h(m\Delta t, n\Delta t) = \left[\frac{T_{i+1} - n\Delta t}{T_{i+1} - T_i} \right] h(m\Delta t, T_i) + \left[\frac{n\Delta t - T_i}{T_{i+1} - T_i} \right] h(m\Delta t, T_{i+1}) \quad (5)$$

where $T_i \leq n\Delta t < T_{i+1}$.

Now with change of variables $n\Delta t - T_i = p\Delta t$, Equation 5 may be written

$$h(m\Delta t, T_i + p\Delta t) = \left[\frac{M-p}{M} \right] h(m\Delta t, T_i) + \left[\frac{p}{M} \right] h(m\Delta t, T_{i+1}) \quad (6)$$

where $T_{i+1} - T_i = M\Delta t$ has been used in obtaining Equation 6.

Equation 6 can be further manipulated to give

$$h(m\Delta t, T_i + p\Delta t) = h(m\Delta t, T_i) + \frac{p}{M} [h(m\Delta t, T_{i+1}) - h(m\Delta t, T_i)] \quad (7)$$

The term within the square brackets defines an incremental filter:

$$\Delta h(m\Delta t, T_i) = \frac{h(m\Delta t, T_{i+1}) - h(m\Delta t, T_i)}{M} \quad (8)$$

Then Equation 7 may be written as

$$h(m\Delta t, T_i + p\Delta t) = h(m\Delta t, T_i) + p\Delta h(m\Delta t, T_i) \quad (9)$$

35 for

$$p=0, 1, \dots, M-1.$$

This last form mathematically represents continuously varying the filters with time or index p between gates T_i and T_{i+1} shown

in FIGURES 4 and 5. Note both the original filter set $h(m\Delta t, T_i)$ and the incremental filters $\Delta h(m\Delta t, T_i)$ derived therefrom may be stored in the computer and brought into operation at the appropriate time. Also, the filter for time $(p+1)\Delta t$ may be obtained from the p th filter by the recursive relationship

$$h[m\Delta t, T_i + (p+1)\Delta t] = h(m\Delta t, T_i + p\Delta t) + \Delta h(m\Delta t, T_i), \quad (10)$$

$p=0, 1, 2, \dots, M-1.$

50 Thus for a filter N points long, each new filter may be obtained from the previous one by only N additions. This operation is considerably faster than trying to implement

Equation 5 as it stands since it would require at least $2N$ multiplications and additions per new filter.

The term "atomic trace" as used herein

refers to an electrical signal having a continuous time function (analog) such as that obtained from the output of a seismometer responsive to seismic waves or refers to an electrical signal or signals digitally representing said continuous time function or a recording of either form. The digital representation of an analog signal involves sampling the analog signal at successive points along the analog signal, which points are spaced in time according to the sampling interval Δt . The sampled values are then encoded into digital form, thereby producing a digitized seismic trace.

WHAT WE CLAIM IS:—

1. Apparatus for time varying filtering of a seismic trace, including a first time domain filter which is optimum for filtering a seismic trace at a first record time and a second time domain filter which is optimum for filtering said trace at a later record time, and means operable to vary the weight of the output of at least one of the filters during the interval between the first and later record times in accordance with a linear function of time.

2. Apparatus according to Claim 1, wherein means are provided for varying the weight of the output of said first filter linearly with respect to the weight of the output of said second filter over said interval between the first and later record times.

3. Apparatus according to Claim 2, wherein said means for varying the weight of the output of said first filter linearly with respect to the weight of the output of said second filter respectively linearly decreases the weight of the output of said first filter over said interval from maximum to zero, and linearly increases the weight of the output of said second filter from zero to maximum over said interval.

4. Apparatus according to Claim 3, wherein said first and second filters are successive filters in a set which are uniquely and individually tailored to filter respective successive data gates located at greater record times along a seismic trace, and further including means for producing said seismic trace, and means for applying said filters successively to said trace, such that the weight of the output of each filter is varied from a minimum to a maximum and back to a minimum in a record time interval centered on the gate to which each filter is uniquely related, which record time interval is equal to twice the length of said gate.

5. Apparatus according to Claim 4, wherein said means for varying the weights of the outputs of said filters is effective to cause the variation of the weight of the output of each said filter to be linear from zero to one and linear from one back to zero.

6. Apparatus according to Claim 4, wherein said successive filters are uniquely constructed to attenuate unwanted components

from said successive data gates which comprise two adjacent data gates along a seismic trace, said seismic trace-producing means providing said seismic trace for at least said two adjacent data gates, and further including a first control means for varying the weight of the output of the first of said filters from zero to one and back to zero during a time interval twice the length of the first of said gates and centered at the center of the first of said gates, and a second control means for varying the weight of the output of the second of said filters from zero to one and back to zero during a time interval twice the length of the second of said gates and centered at the center of the second of said gates.

7. Apparatus according to Claim 4, wherein said seismic trace-producing means provides said seismic trace for all available data gates, and said first and second filters are included in a plurality of filters each having fixed filter elements uniquely and individually tailored to a particular data gate of said seismic trace, two successive filters being applied by said filter-applying means to said seismic trace with said successive filters being uniquely and individually tailored to adjacent data gates, and the weights of the outputs of said plurality of filters being varied in subsets taken two at a time by said weight-varying means, such that at any one instant of time, the weight of the output from one filter in each of said subsets is being varied linearly in direction from one to zero while the weight of the output of the other filter of each said subset is being varied linearly in direction from zero to one.

8. Apparatus according to any preceding claim, further including means for summing the weighted outputs of said filters.

9. Apparatus according to Claim 8, wherein said weight-varying means for said filters comprises respective variable resistors in series with the output of the filter corresponding thereto and said summing means.

10. Apparatus according to Claim 9, as dependent from any of claims 4 to 7, further including means for synchronizing the variation of said variable resistors with the operation of said seismic trace-producing means.

11. The method of continuously time varying filtering a seismic trace which comprises: applying two different time domain filters to the seismic trace wherein one time domain filter is optimum for filtering the seismic trace at a first record time and the other time domain filter is optimum for filtering the seismic trace at a later record time, and varying the weight of the output of at least one of the filters during the interval between the first and later record times in accordance with a linear function of time.

12. The method according to Claim 11, wherein the weights of the outputs of said

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refers to an electrical signal having a continuous time function (analog) such as that obtained from the output of a seismometer responsive to seismic waves or refers to an electrical signal or signals digitally representing said continuous time function or a recording of either form. The digital representation of an analog signal involves sampling the analog signal at successive points along the analog signal, which points are spaced in time according to the sampling interval Δt . The sampled values are then encoded into digital form, thereby producing a digitized seismic trace.

15 WHAT WE CLAIM IS:—

1. Apparatus for time varying filtering of a seismic trace, including a first time domain filter which is optimum for filtering a seismic trace at a first record time and a second time domain filter which is optimum for filtering said trace at a later record time, and means operable to vary the weight of the output of at least one of the filters during the interval between the first and later record times in accordance with a linear function of time.

2. Apparatus according to Claim 1, wherein means are provided for varying the weight of the output of said first filter linearly with respect to the weight of the output of said second filter over said interval between the first and later record times.

3. Apparatus according to Claim 2, wherein said means for varying the weight of the output of said first filter linearly with respect to the weight of the output of said second filter respectively linearly decreases the weight of the output of said first filter over said interval from maximum to zero, and linearly increases the weight of the output of said second filter from zero to maximum over said interval.

4. Apparatus according to Claim 3, wherein said first and second filters are successive filters in a set which are uniquely and individually tailored to filter respective successive data gates located at greater record times along a seismic trace, and further including means for producing said seismic trace, and means for applying said filters successively to said trace, such that the weight of the output of each filter is varied from a minimum to a maximum and back to a minimum in a record time interval centered on the gate to which each filter is uniquely related, which record time interval is equal to twice the length of said gate.

5. Apparatus according to Claim 4, wherein said means for varying the weights of the outputs of said filters is effective to cause the variation of the weight of the output of each said filter to be linear from zero to one and linear from one back to zero.

6. Apparatus according to Claim 4, wherein said successive filters are uniquely constructed to attenuate unwanted components

from said successive data gates which comprise two adjacent data gates along a seismic trace, said seismic trace-producing means providing said seismic trace for at least said two adjacent data gates, and further including a first control means for varying the weight of the output of the first of said filters from zero to one and back to zero during a time interval twice the length of the first of said gates and centered at the center of the first of said gates, and a second control means for varying the weight of the output of the second of said filters from zero to one and back to zero during a time interval twice the length of the second of said gates and centered at the center of the second of said gates.

7. Apparatus according to Claim 4, wherein said seismic trace-producing means provides said seismic trace for all available data gates, and said first and second filters are included in a plurality of filters each having fixed filter elements uniquely and individually tailored to a particular data gate of said seismic trace, two successive filters being applied by said filter-applying means to said seismic trace with said successive filters being uniquely and individually tailored to adjacent data gates, and the weights of the outputs of said plurality of filters being varied in subsets taken two at a time by said weight-varying means, such that at any one instant of time, the weight of the output from one filter in each of said subsets is being varied linearly in direction from one to zero while the weight of the output of the other filter of each said subset is being varied linearly in direction from zero to one.

8. Apparatus according to any preceding claim, further including means for summing the weighted outputs of said filters.

9. Apparatus according to Claim 8, wherein said weight-varying means for said filters comprises respective variable resistors in series with the output of the filter corresponding thereto and said summing means.

10. Apparatus according to Claim 9, as dependent from any of claims 4 to 7, further including means for synchronizing the variation of said variable resistors with the operation of said seismic trace-producing means.

11. The method of continuously time varying filtering a seismic trace which comprises: applying two different time domain filters to the seismic trace wherein one time domain filter is optimum for filtering the seismic trace at a first record time and the other time domain filter is optimum for filtering the seismic trace at a later record time, and varying the weight of the output of at least one of the filters during the interval between the first and later record times in accordance with a linear function of time.

12. The method according to Claim 11, wherein the weights of the outputs of said

5 filters are simultaneously varied in opposite senses as predetermined linear functions of the time scale of said trace, and further including summing the weighted outputs of said filters.

13. The method according to Claim 12, wherein the weights of the outputs of said filters are varied at the same rate.

10 14. The method according to any one of claims 11 to 13, further including forming a set of seismic filters comprising said two different time domain filters where each filter in said set is uniquely related to a different data gate or two successive data gates of said seismic trace, and the application
15 of said filters to said trace being accomplished by applying said set of filters such that at any one instant of time the weight of the output from one filter is being varied linearly in direction from one to zero while the weight
20 of the output of the other filter is being varied linearly in direction from zero to one.

15 15. The method according to claim 14, wherein the variation of the weight of the output from one filter begins coincident with the beginning of the variation of the weight of the output from the other filter.

30 16. The method according to either of Claims 14 or 15, wherein a plurality of successive data gates $a, b, \dots, n$ of said seismic trace are provided, and further including establishing for each of a plurality of said successive data gates $a, b, \dots, n$ of said seismic

trace, time domain filters $f_a, f_b, \dots, f_n$ peculiarly tailored to improve the signal-to-noise ratio in data gates $a, b, \dots, n$, respectively, said filters being applied to said seismic trace variably in accordance with the pattern f_a and f_b to data gate a , f_b and f_c to data gate b ,... and the varying of the weights of the outputs of said filters occurring over a range from zero to one and back to zero and being accomplished over a time interval twice the length of said data gates with filter f_a having the weight of one at the center of data gate a , filter f_b having the weight of one at the center of data gate b ,... and filter f_n having the weight of one at the center of data gate n .

17. Apparatus for time varying filtering of a seismic trace substantially as described herein with reference to and as illustrated by Figures 1 to 3 or Figures 4 and 5 of the accompanying drawings.

18. A method according to claim 11, substantially as described herein with reference to the accompanying drawings.

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