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(71) Applicant: **MOBIL OIL CORPORATION**
150 East 42nd Street
New York New York 10017(US)

(72) Inventor: Ballard, Billy Gene
402 East Monica Drive
Garland, Texas 75041(US)

(72) Inventor: Dennis, Charles Louis
627 Kindred
Richardson Texas 75080(US)

(72) Inventor: Williams, Donald Michael
2341 Mockingbird Drive
Grapevine Texas 76051(US)

(74) Representative: West, Alan Harry
Mobil Court 3 Clements Inn
London WC2A 2EB(GB)

(54) Method and apparatus for digitizing the maximum amplitude and time occurrence of an acoustic signal.

(57) Digitizing and transmitting the maximum amplitude and time of occurrence of an analog signal is proposed for borehole televiewing apparatus to reduce the amount of data transmitted from a borehole tool to surface imaging equipment. During at least one established time window, the analog signal is amplitude sampled with an analog-to-digital converter 11. Each sample value is fed to a comparator 15 and compared with a previously stored maximum amplitude sample value and, if the present sample is greater than stored, it is stored as the new maximum amplitude sample value. Whenever a new maximum amplitude sample value is stored, its time of occurrence is also stored. At the end of each time window digital data representing the maximum amplitude and its time of occurrence are available for transmission so as to allow reconstruction of the original analog signal.

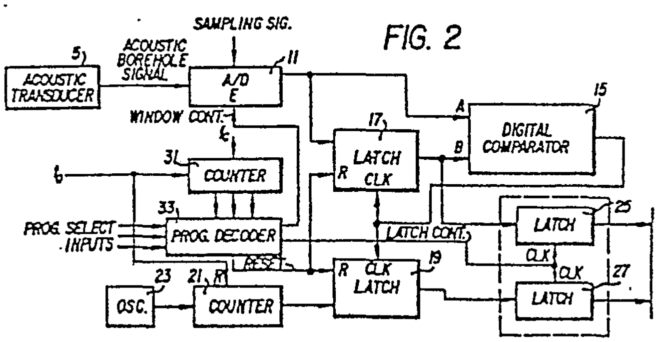

FIG. 2

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METHOD AND APPARATUS FOR DIGITIZING THE MAXIMUM AMPLITUDE AND TIME OCCURRENCE OF AN ACOUSTIC SIGNAL

The present invention relates to a method and apparatus for digitizing the maximum amplitude and time occurrence of an acoustic signal and, more particularly, of an acoustic signal produced in a borehole televiewing apparatus.

Borehole televiewing apparatus is commonly used to produce an image representing the physical characteristics of the inside surface of a borehole. Typically, a borehole transducer positioned within a borehole tool transmits an acoustic pulse into the borehole in a scanning period. The acoustic pulse is reflected by the borehole wall and received by a receiver/detector in the tool, which, in turn, transmits the envelope of the reflected signal to a recording and/or imaging apparatus located at a surface location. Incremental rotative movement of the transducer about the borehole for each of a plurality of successive scanning periods produces reflection signals which can be used to produce a representative image of the borehole wall structure, which may be recorded and/or displayed on a cathode ray tube. Representative borehole televiewer devices are described and illustrated in U. S. Patent Nos. 3,668,619 and 3,369,626.

In a borehole televiewing apparatus, an analog signal path is provided from the envelope detector in the borehole tool to the surface recording and/or image display devices. Analog signal transmission presents problems in that the attenuation characteristics of the transmission lines limit the dynamic range of, and thus distort, the transmitted signal, making it difficult to obtain high quality raw data at the surface equipment. One way of improving the fidelity of the transmitted signal is to digitize it at the borehole tool and transmit only digital data to the surface equipment. However, the scanning frequency of the transmitter/receiving apparatus is typically quite high, e.g., 2,000 scanning periods per second, and a high sampling frequency is also required, e.g., 500 sampling pulses per scanning period, to faithfully reproduce a high quality image at the surface. If 8 bits of data are required for each sample, then (8 bits) x (500 samples/period) x (2,000 periods/sec) = 8M bits/sec of data must be transmitted to the surface, which considerably exceeds the capability of present digital wire pair telemetry systems, making digitization of the detected reflection pulse signal impractical. An object of the present invention is therefore to obviate or minimize this problem.

Accordingly, the invention resides in one aspect in a method for determining the maximum amplitude and its time of occurrence of an analog signal comprising:

defining at least one time window within which said analog signal is expected to occur;

generating a timing signal representing elapsed time from a predetermined start time;

analog-to-digital converting and sampling said analog signal during said time window to produce successive digital sample values representing the amplitude of said analog signal;

comparing during said time window a present digital sample value S_n with a previously stored digital sample value S_{n-x};

storing value S_{n-x} when said present sample value S_n is greater than said previously stored sample value; and,

storing the present value of said timing signal when a said present sample value S_n is stored as said previously stored sample value S_{n-x}.

In a further aspect, the invention resides in apparatus for determining the maximum amplitude and its time of occurrence of an analog signal comprising:

means for defining at least one time window within which said analog signal is expected to occur;

means for generating a digital timing signal representing elapsed time from a predetermined start time;

means for analog-to-digitally converting and sampling said analog signal during said timing window, to produce successive digital sample values representing the amplitude of said analog signal;

means for comparing a present sample S_n value with a previously stored sample value S_{n-x};

means responsive to said comparing means for storing a present sample value S_n as said previously stored sample value S_{n-x} when said present sample value S_n is greater than said previously stored sample value; and,

means responsive to said comparing means for storing the present value of said timing signal when said present sample S_n is stored as said previously stored sample value.

In the accompanying drawings in which:

Fig. 1 is a signal amplitude vs. time diagram useful in explaining the invention;

Fig. 2 is a block diagram representing digitizing apparatus according to one example of the invention;

Fig. 3 is a signal amplitude vs. time diagram useful in explaining a modified digitizing apparatus;

Fig. 4 is a block diagram illustrating a borehole televiewing apparatus;

Fig. 5 is a block diagram representation of a first embodiment of surface apparatus for reconstructing a properly timed analog amplitude signal;

Fig. 6 is an amplitude vs. time diagram of a reconstructed analog signal;

Figs. 7a, 7b and 7c are timing diagrams useful in explaining a second embodiment of surface apparatus for reconstructing a properly timed analog amplitude signal;

Figs. 8a, 8b and 8c are signal formal diagrams useful in explaining the second embodiment of the surface reconstruction apparatus;

Fig. 9 is a block diagram showing a modification of the Fig. 2 digitizing apparatus for use with the second embodiment of the surface reconstruction apparatus; and

Fig. 10 is a block diagram representation of the second embodiment of the surface reconstruction apparatus.

Referring to Figs. 1 and 4, in a borehole televiewing apparatus an acoustic pulse signal P (Fig. 1) is transmitted from a transducer 5 located in a borehole tool 1 (Fig. 4) by means of a pulse generator 3 at a time t_0, which defines the beginning of a scanning period $t_0...t_{0+1}$. The transmitted signal P is reflected by the borehole peripheral surface back to the borehole tool as a reflected acoustic pulse signal R during the scanning period and is detected by transducer 5. An additional echo signal R' generated from reflections beyond the borehole wall also typically occur during the scanning period and it too is detected by transducer 5. Other reduced amplitude miscellaneous reflection signals and noise components R" may also be present in the signal received and detected by transducer 5.

Both the maximum amplitude of the reflected pulse signal R, as well as the time of its occurrence during each scanning period $t_0...t_{0+1}$, are digitized and transmitted to surface equipment 10 by a digitizing apparatus 7. The maximum amplitude and time of occurrence data are sequentially transmitted to surface equipment 10 over conventional well logging transmission lines 9 by means of a multiplexer 6 and data encoder 8, e.g., a manchester data encoder. Apparatus at the surface receives the maximum amplitude and time of occurrence data and reconstructs an analog signal therefrom, which can be used in a conventional borehole televiewer display apparatus to construct an image of the borehole interior wall structure.

Fig. 2 illustrates in greater detail the digitizing apparatus 7 for digitizing the maximum amplitude and time of occurrence of the reflected acoustic pulse signal R. The reflected acoustic pulse signal R detected by acoustic transducer 5, is applied to the analog input of a high speed sampling analog-to-digital converter 11. A high frequency sampling input signal consisting of typically 100ns pulses, is applied to the sampling input of converter 11, while a window control signal is applied to an enabling input of converter 11 from a programmable decoder 33. The window control signal enables converter 11 and establishes a time window W (from time t_1 to time t_2 in Fig. 1), during which the apparatus of Fig. 2 operates to "look for" the reflected acoustic pulse signal R. The time window W is established where the reflected signal R is expected to occur. The time of its beginning, as well as its duration, are empirically determined to ensure that it encompasses the reflected acoustic pulse signal R. The window W may be as wide as a scanning period, i.e., $t_0 \ldots t_{0+1}$, but as a practical matter, it is typically shorter, as shown in Fig. 1.

The window control signal is generated automatically a predetermined period of time after an acoustic pulse P is transmitted into the borehole by the borehole tool, i.e., a predetermined period of time after t_0, for example, by a counter 31 counting a clock frequency f_c and feeding the programmable decoder 33 which decodes the output of counter 31 and generates, at the appropriate time, the window control signal. The timing cycle for operation of counter 31 and decoder 33 is the scanning period $t_0 \ldots t_{0+1}$. Accordingly, counter 31 is reset at the beginning of each scanning period by a signal t_0 generated thereat by the pulse generator 3. The programmable decoder 33 may be, for example, a Harris HM-7616 PROM, or a programmable logic array. Decoder 33 produces the window control signal and other output signals described below at predetermined times, in accordance with program selection inputs thereto and the monitored output of counter 31. To change the timing of the window control signal and the other output signals, the program selection inputs are changed. For convenience, the program selection inputs to decoder 33 are controlled by the surface equipment 10 which interconnects with decoder 33 by transmission lines 9 (Fig. 4) of a well logging cable. The timing signals generated by decoder 33 include the window control signal, as well as latch control and reset control signals discussed in greater detail below.

The digitizing apparatus also includes a digital comparator 15 which continually compares a current amplitude sample value S_n

from converter 11 (the A input to comparator 15) with a previously stored amplitude value S_{n-x} (the B input to comparator 15) stored in a latch 17. Whenever the current sample value S_n exceeds the previously stored value S_{n-x} (input A | input B), the comparator applies an enabling signal to latches 17 and 19 which causes latch 17 to store the current sample value S_n as the stored sample value, which is then used for comparison with subsequent current sample values S_n occurring during the time window W.

As a result of the continued and combined operation of converter 11, comparator 15 and latch 17, latch 17 will, at the end of time window W, contain an amplitude value representative of the peak amplitude of reflected signal R. The time of occurrence of the peak amplitude is determined by counter 21 which counts the output pulses from an oscillator 23. Counter 21 is reset at the beginning of a scanning period by means of the signal t_0, so that the counter 21 contains a value representing the instantaneous time (or running time) following the time t_0. The output of counter 21 is applied to latch 19 and, whenever comparator 15 determines that a present amplitude value sample S_n is to be stored in latch 17, it causes latch 19 to store the time of occurrence of that sample value in latch 19. Accordingly, at the end of time window W, latch 19 contains time of occurrence information for the maximum amplitude sample value then stored in latch 17.

At the end of time window W, the window control signal from decoder 33 is removed from the enable input to converter 11, which effectively stops operation of the Fig. 2 circuit as no new sample values can be generated.

The data stored in latches 17 and 19 is stored for transmission to surface equipment 10 after the end of time window W by a latch control signal applied to latches 25, 27 which respectively receive and store for transmission the contents of latches 17 and 19. The latch control signal is generated by decoder 33 after the transmission of time window W.

Although Fig. 2 illustrates an apparatus in which a single time window W is employed, the illustrated apparatus can also be used with a plurality of time windows $W_1 \ldots W_n$ of, for example, the same duration within a scanning period $t_0 \ldots t_{0+1}$, as shown in Fig. 3. For operation with a plurality of time windows $W_1 \ldots W_n$, a different programming of decoder 33 is selected by the programming inputs thereto so that suitable time window control, latch control and reset control signals are generated for each timing window. Counter 21 need not be reset for each time window, but is reset once for each scanning period $t_0 \ldots t_{0+1}$, at time t_0, as described earlier.

The use of successive time windows for a scanning time period $t_0 \ldots t_{0+1}$ allows for isolation and digitization of not only the maximum amplitude and time of occurrence of the principle reflected signal R, but also of additional reflected signal components, such as the echo signal R' and other later reflections R''' (Fig. 3), should digitization and transmission of these signals be desired.

For transmission to surface equipment 10, the paired digital amplitude and time of occurrence data stored in latches 25 and 27 are multiplexed by multiplexer 6 (Fig. 4) and encoded by an encoder 8, e.g., a manchester encoder, and then sent over transmission lines 9. In the borehole tool, one bit of an encoded data word is encoded by encoder 8 as a flag bit in response to operation of multiplexer 6 to indicate whether the encoded word contains amplitude data, e.g., a "1" flag bit encoding, or time of occurrence data, e.g., a "0" flag bit encoding.

Fig. 5 illustrates the apparatus employed in surface equipment 10 for reconstructing an analog signal having an amplitude and time of occurrence corresponding to the digital amplitude and time of occurrence data produced by the Fig. 2 apparatus. The surface apparatus includes a decoder 41, e.g., a manchester decoder which receives the encoded data from the apparatus and which produces a conventional "valid word" output whenever it recognizes that a valid encoded data word (either amplitude or time of occurrence data) has been received. The "valid word" output of decoder 41 enables a flag detector 43, which examines a flag bit in the decoded word, to determine whether it contains amplitude or time of occurrence information. The flag detector 43 loads the decoded data word into a down counter 45 by enabling the counter 45 if the data word represents time of occurrence data, and loads the data word into a latch 47 by enabling latch 47 if the data word represents amplitude data.

When loaded with a new data word, down counter 45 immediately begins deincrementing the loaded count value by means of a clocking signal input thereto until a predetermined count value, e.g., zero, is reached, at which time a one-shot multivibrator 49 is enabled. The output of one-shot multivibrator 49 is used to enable a digital-to-analog converter 51, which converts the digital amplitude data stored in latch 47 into an analog signal value on output line 53. The reconstructed analog signal is shown in Fig. 6. The analog signal generated on output line 53 has an amplitude value corresponding to the maximum analog signal amplitude value digitized in the borehole tool, with time of occurrence from a predetermined start time, e.g., t_0, corresponding to the time of occurrence of the maximum analog signal amplitude digitized in the borehole tool. A characteristic of the Fig. 5 reconstruction apparatus is that it is not necessary separately to transmit or receive information representing the start time of a scanning period, e.g., t_0, as this information is implicitly contained in the time of occurrence data. That is, whenever down counter 45 is loaded with new timing data it restarts a time period which expires when counter 45 counts to a preset value, which represents the time of occurrence of the maximum amplitude data signal from the scanning period start time t_0. The analog output on line 51 may be used by a conventional borehole televiewing apparatus to record and reconstruct an image representing the physical characteristics of the inside surface of a borehole.

The reconstruction apparatus illustrated in Fig. 5 is intended to operate with one time window in a scanning period $t_0 \ldots t_{0+1}$, and cannot easily be adapted for use with a plurality of time windows. An alternative reconstruction apparatus for use with one, two or four time windows during a scanning period is shown in Fig. 10. The Fig. 10 apparatus is used in conjunction with the data transmission format shown in Fig. 8, which will be described first.

The signal transmitted from the borehole tool-to-surface receiving equipment 10 for use with the one, two or four window reconstruction of Fig. 10 has the data format illustrated in Fig. 8. Each scanning period $t_0 \ldots t_{0+1}$ of, e.g., 500us, is divided into a frame of the same time period, e.g., 500us, containing four equal duration data block $D_1 \ldots D_4$. Each data block contains paired maximum amplitude (A) data and corresponding time of occurrence (T) data.

For a one window system, illustrated in Fig. 7a, the maximum amplitude and time of occurrence data (A_1, T_1) is repeated during transmission to the surface in each of the data blocks $D_1 \ldots D_4$. For a two window system, illustrated in Fig. 7b, the paired amplitude and time of occurrence data (A_1, T_1) for the first window is repeated in the first two data blocks D_1 and D_2, while the same data for the second window (A_2, T_2) is repeated in the last two data blocks D_3 and D_4. For a four window system, illustrated in Fig. 7c, each data block $D_1 \ldots D_4$ contains pair amplitude and time values corresponding to respective windows, e.g., A_1, T_1; A_2, T_2; A_3, T_3; A_4, T_4.

The data frames illustrated in Fig. 8 are formed by the apparatus illustrated in Fig. 9, which is a modification of the Fig. 4 borehole tool apparatus 1. The data frame is formed in a parallel to serial frame register 63. Sequential paired amplitude and time data from encoder 8 are loaded into the various stages of register 63 by way of loading gates 61. The program selection inputs to decoder 33, which select the number of timing windows in the Fig. 2 digitizing apparatus are used to operate loading gates 61 so that one of the data formats illustrated in Fig. 8a, 8b or 8c is created in frame register 63, corresponding to a surface selection of one, two or four timing windows. The serial output of frame register 63 is applied to transmission lines 9 for transmission to the surface apparatus illustrated in Fig. 10.

The Fig. 10 apparatus is designed to receive any one of the selected data formats shown in Figs. 8a, 8b or 8c and reconstruct therefrom, the maximum amplitude and time of occurrence data for each of the time windows used in the system. Incoming encoded data is decoded by decoder 83 and then loaded frame-by-frame serially into a frame receiver register 67. To simplify further discussion, it will be assumed, for the moment, that four windows have been selected by the programming inputs to decoder 33 and loading gates 61. The causes register 67 to have a loaded data format, wherein each data block $D_1 \ldots D_4$ contains paired amplitude and time data for a respective time window $W_1 \ldots W_4$. The parallel outputs of register 67 are applied to a data select circuit 69 having ganged switches 71a and 71b. Switch 71a sequentially connects each of the amplitude values $A_1 \ldots A_4$ to an output line O_1, while switch 71b sequentially connects each of the timing values $T_1 \ldots T_4$ to an output line O_2. Consequently, as switches 71a, 71b sequentially move, paired amplitude A and timing T data are applied to output lines O_1 and O_2 of data select circuit 69. Switches 71a and 71b move in unison in response to a command signal from sequencer 73, which is generated with a period of $t_0/4$, that is, four times in a scanning period $t_0 \ldots t_{0+1}$. Assuming a scanning period of 500μs, the command signals occur every 125μs. Thus, during the frame time of 0-500μs data is available at the output lines O_1, O_2 of selector 69 as follows:

	O_1, O_2
0-125μs	A_1, T_1
125-250μs	A_2, T_2
250-375μs	A_3, T_3
375-500μs	A_4, T_4

The command signals begin when sequencer 73 is informed by the output of frame detector 81 that a frame of data is present in register 67. To reconstruct both the maximum amplitude and its time of occurrence for each of the four windows $W_1...W_4$, a comparator 71, time base counter 73, oscillator 85, coincidence gate 75 and digital-to-analog converter 77 are employed. Time base counter 73 is reset by a signal t_B at the beginning of a scanning period of the signal reconstruction apparatus. This scanning period is equal in duration to that used in the borehole tool, i.e., $t_0...t_{0+1}$, but its initiation need not coincide with that of the scanning period in the borehole tool. Once reset by signal t_B, time base counter 73 begins counting the output of oscillator 85. Comparator 71 receives the count value from counter 73 and compares it with a timing value then present at the O_2 output line of data select circuit 69. Whenever comparator 71 detects a coincidence between a timing value and the output of counter 73, it supplies an enable signal to gate 75 which allows a maximum digital amplitude value A corresponding to the timing value to pass to digital-to-analog converter 77, where the maximum amplitude value is reconstructed at a proper time with respect to the beginning t_B of a scanning frame in the reconstruction apparatus. For a four window system, the paired digital values A_1, T_1; A_2, T_2; A_3, T_3; and A_4, T_4 will be sequentially connected to the data selector 69 outputs by the command signal and the maximum amplitude values $A_1...A_4$ will be reconstructed, in properly timed sequence in a scanning period by the timing values $T_1...T_4$.

As noted, the Fig. 10 apparatus can also be used with a one or two window system as well. For a one window system, each of the four data blocks loaded into register 67 will have the same data A_1, T_1, as shown in Fig. 8a. As a result, although the data select circuit 69 sequentially applies the A_1 and T_1 data from each of the data blocks to output line O_1 and O_2, comparator 71 will still only provide one output signal when it determines coincidence between T_1 and the output of counter 73, no matter which data block $D_1...D_4$ switch 71 is then examining, so that a maximum amplitude output properly timed with respect to the beginning t_B of a reconstruction scanning frame is produced by digital-to-analog converter 77.

Similarly, when two windows are employed and the transmitted data format for the four data blocks $D_1 \ldots D_4$ is as shown in Fig. 8b, comparator 71 will recognize only two timing values T_1 and T_2 and will appropriately enable gate 75 so that corresponding maximum amplitude values A_1 and A_2 will be applied at the proper time to converter 77 and reconstructed.

For proper operation of the Fig. 10 apparatus, counter 21 in the digitizing apparatus is reset only at the beginning of a new scanning period, i.e., at t_0, so that each timing value T in a scanning period $t_0 \ldots t_{0+1}$ has a different value.

As is apparent, the Fig. 10 reconstruction apparatus is capable of use in a system employing one, two or four timing windows during a scanning period $t_0 \ldots t_{0+1}$. It should be apparent that other reconstruction apparatus could be easily devised for other numbers of timing windows.

CLAIMS:

1. A method for determining the maximum amplitude and its time of occurrence of an analog signal comprising:

defining at least one time window within which said analog signal is expected to occur;

generating a timing signal representing elapsed time from a predetermined start time;

analog-to-digital converting and sampling said analog signal during said time window to produce successive digital sample values representing the amplitude of said analog signal;

comparing during said time window a present digital sample value S_n with a previously stored digital sample value S_{n-x};

storing value S_{n-x} when said present sample value S_n is greater than said previously stored sample value; and,

storing the present value of said timing signal when a said present sample value S_n is stored as said previously stored sample value S_{n-x}.

2. The method of Claim 1, wherein said analog signal is a reflection signal caused by the generation of an acoustic pulse scanning signal within a borehole and said time window is defined at a time subsequent to generation of said scanning signal.

3. A method for reconstructing the maximum amplitude and time of occurrence of an analog signal wherein said maximum amplitude and time of occurrence are determined by the method of Claim 1, comprising:

receiving said stored sample value representing the maximum amplitude of the analog signal occurring during said at least one time window;

receiving said stored present value of the timing signal representing the time of occurrence of said maximum amplitude during said time window; and,

digital-to-analog converting the received sample value a predetermined period of time after a reference start time, said predetermined period of time being determined by the value of the received timing signal.

4. The method of Claim 3, further comprising the steps of storing said sample value after its receipt, loading said timing signal as preset data into a counter after its receipt, said counter counting a clocking signal, and operating a digital-to-analog converter which converts said stored sample value into an analog signal when said counter reaches a predetermined count value.

5. The method of Claim 3, further comprising the steps of storing said sample value and said timing signal after their receipt, comparing said stored timing signal with the output of a counter counting a clocking signal and generating a control signal when the output of the counter has a predetermined

relationship with respect to the stored timing signal, and digital-to-analog converting the stored sample value when said control signal is generated.

6. An apparatus for determining the maximum amplitude and its time of occurrence of an analog signal comprising:

means for defining at least one time window within which said analog signal is expected to occur;

means for generating a digital timing signal representing elapsed time from a predetermined start time;

means for analog-to-digitally converting and sampling said analog signal during said timing window, to produce successive digital sample values representing the amplitude of said analog signal;

means for comparing a present sample S_n value with a previously stored sample value S_{n-x};

means responsive to said comparing means for storing a present sample value S_n as said previously stored sample value S_{n-x} when said present sample value S_n is greater than said previously stored sample value; and,

means responsive to said comparing means for storing the present value of said timing signal when said present sample S_n is stored as said previously stored sample value.

7. The apparatus of claim 6 and further comprising:

means for digital-to-analog converting said stored sample value a predetermined period of time after a reference start time, said predetermined period of time being determined by said stored timing signal.

FIG. 1

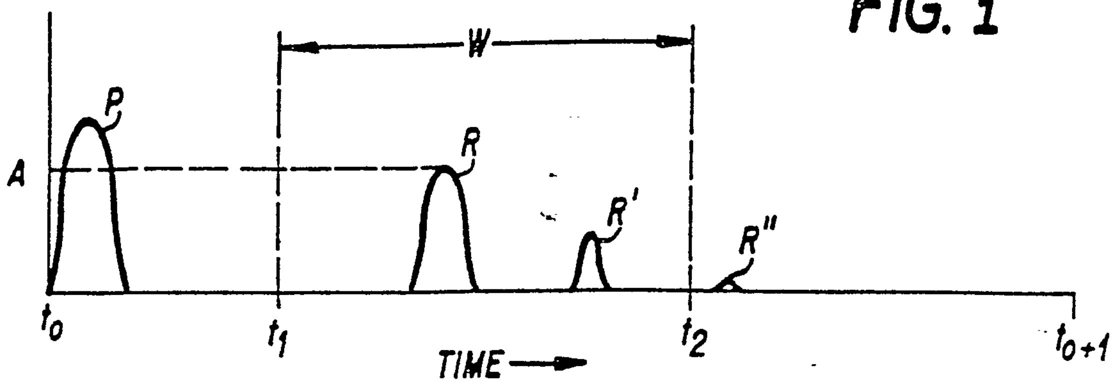


FIG. 2

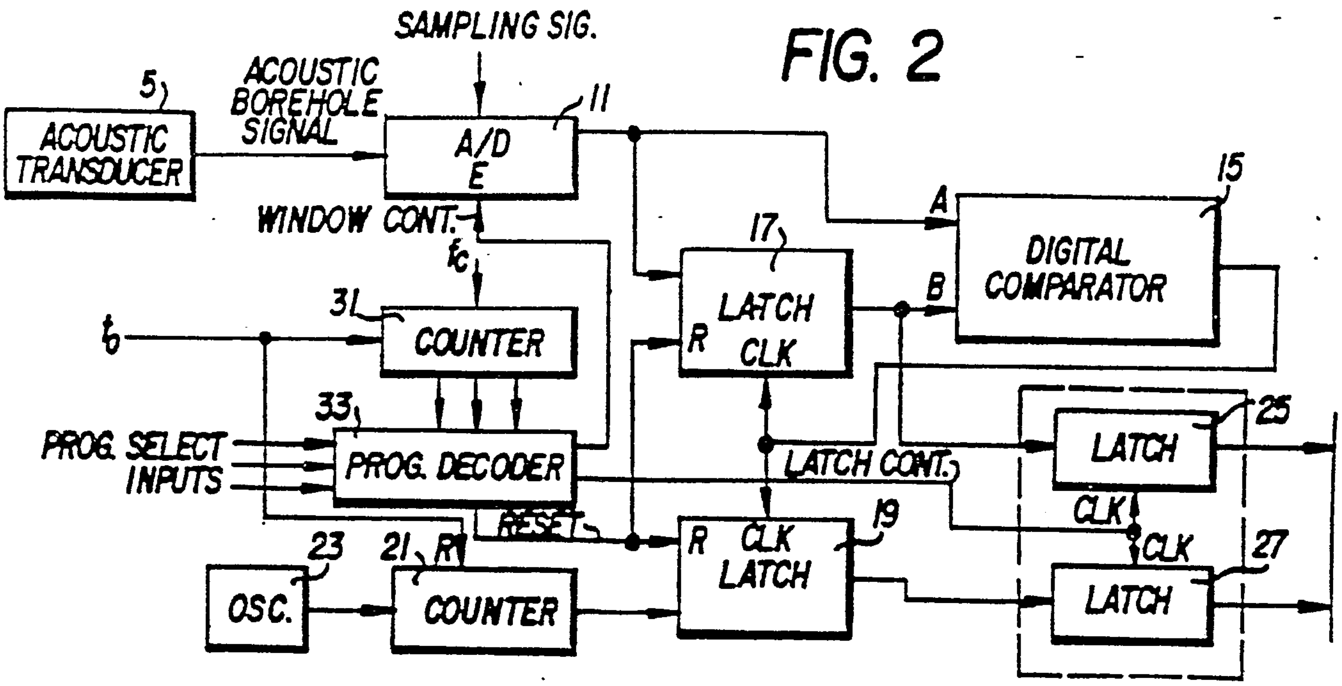


FIG. 3

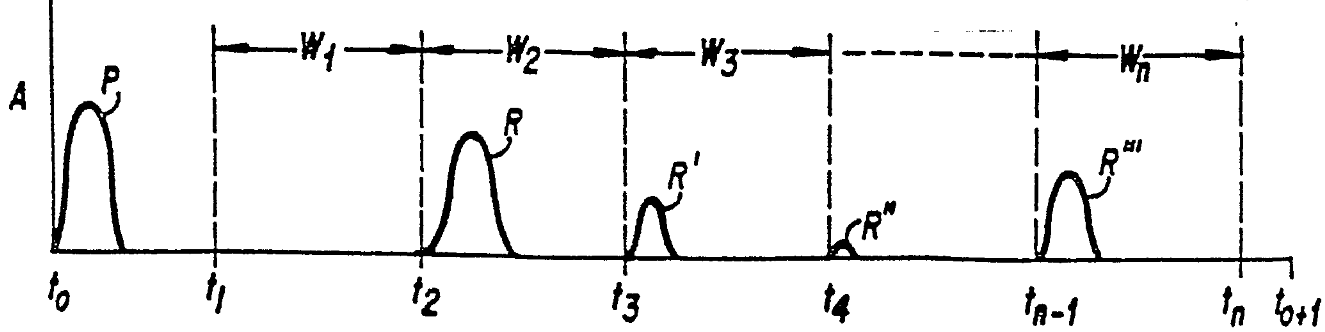
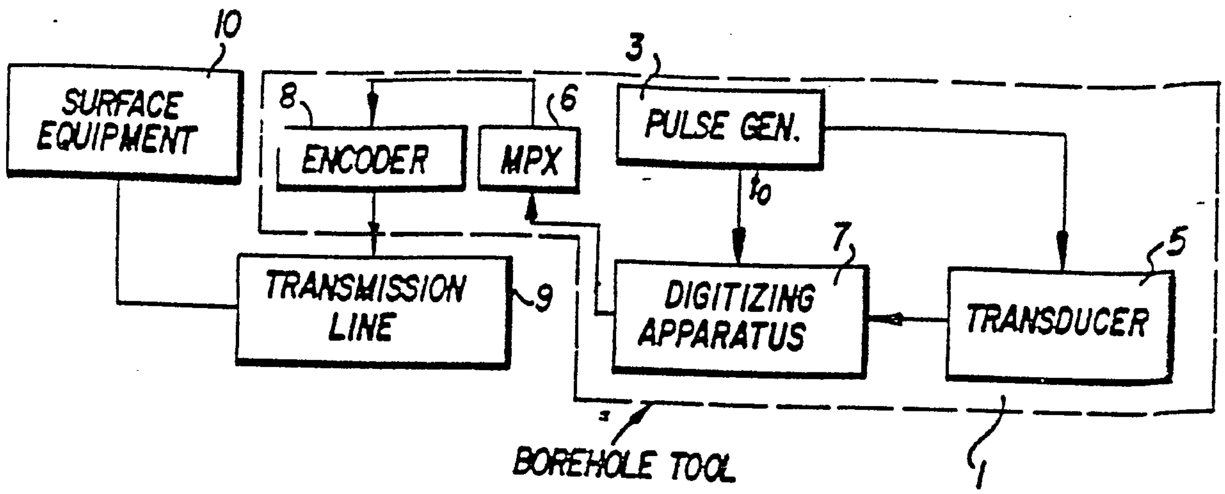


FIG. 4



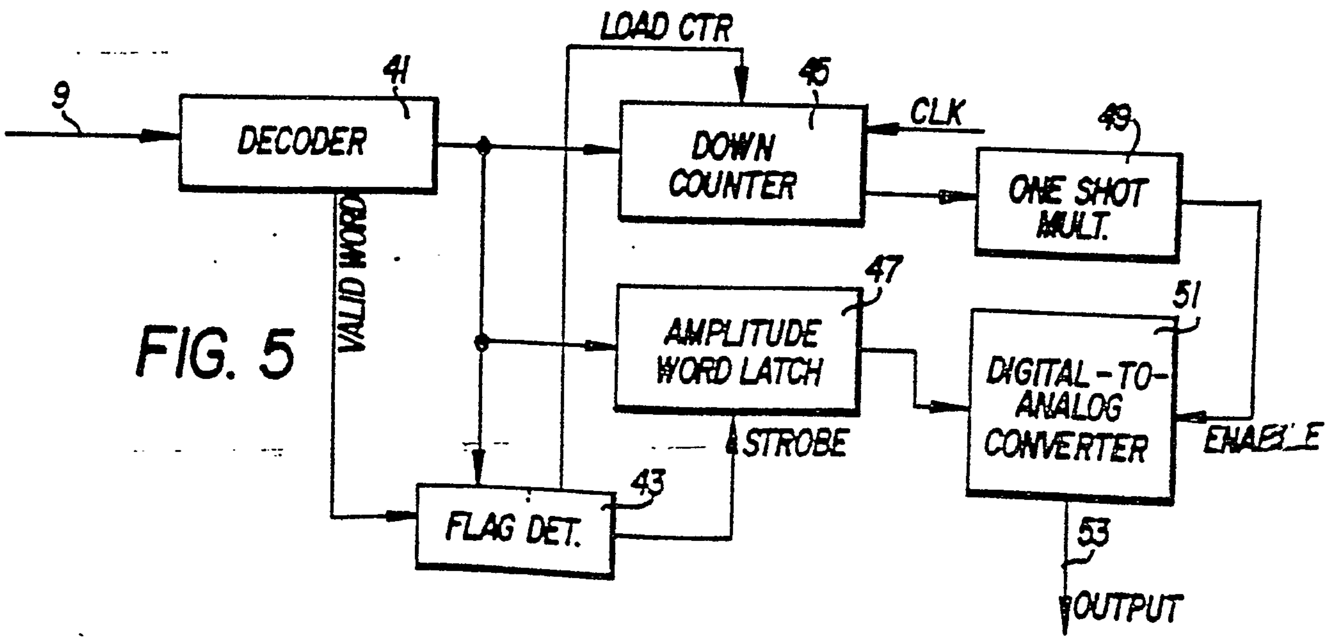
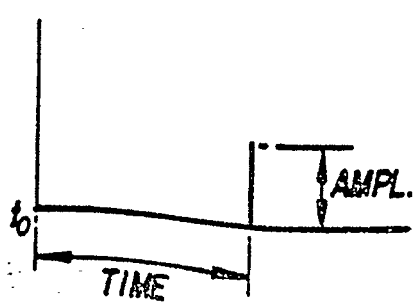


FIG. 5

FIG. 6



WINDOW FORMAT

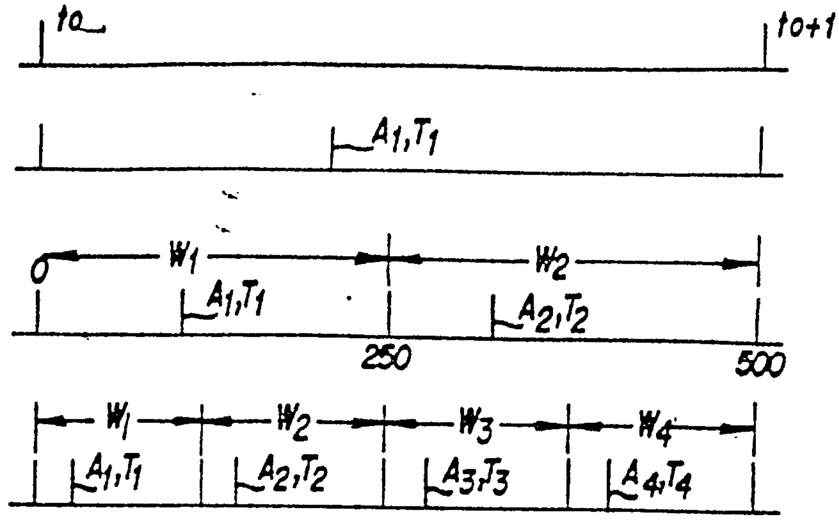


FIG. 7(A)

FIG. 7(B)

FIG. 7(C)

DATA TRANSMISSION FORMAT

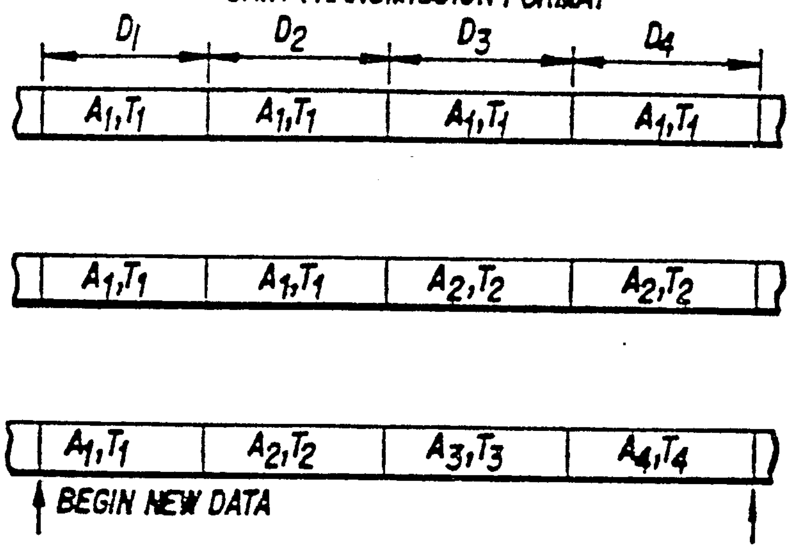


FIG. 8(A)

FIG. 8(B)

FIG. 8(C)

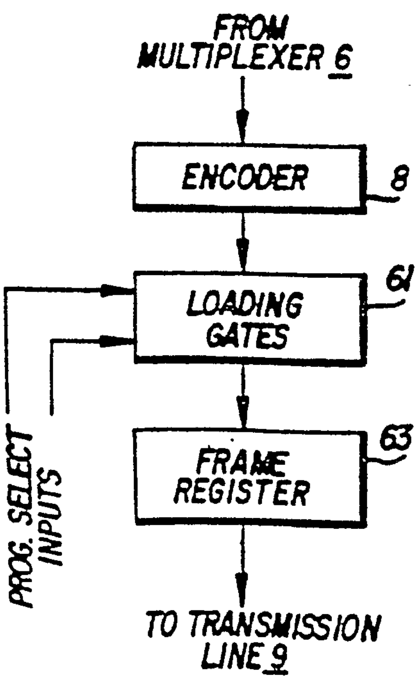


FIG. 9

FIG. 10