

PATENT SPECIFICATION

357 151

135 151

- (21) Application No. 24203/71 (22) Filed 19 April 1971
 (31) Convention Application No. 15790 (32) Filed 2 March 1971
 (33) United States of America (US)
 (44) Complete Specification published 19 June 1974
 (51) International Classification G01D 9/00 9/42
 (52) Index at acceptance
 G4H 13D 14A 14B 1B 23B 6A 6B 6D 7B 7F 9BY 9X
 (72) Inventor JENNINGS W. ELLIOTT



(54) METHODS AND APPARATUS FOR RECORDING WELL LOGGING MEASUREMENTS

(71) We, SCHLUMBERGER INLAND SERVICES INC., a corporation of Panama, 19 Berkeley Street, London, W.1., England, do hereby declare the invention, for which we pray 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 methods and apparatus for processing well logging measurements for recording on a recording medium as a function of the depth at which said measurements were obtained. The invention has special application to recording of well logging data with a cathode ray tube recorder.

In producing well logging measurements, a logging tool containing one or more exploring devices is lowered into a borehole drilled into the earth for measuring various properties of the subsurface earth formations adjacent to a borehole, or properties of the borehole itself. Such measurements are of considerable value in determining the presence and depth of hydrocarbon bearing zones that may exist in the subsurface earth formations.

It is desirable in many instances to provide one or more visible logs of the investigated subsurface phenomena at the well site within a relatively short time after the log has been run. In other cases, it is desirable to transmit the well logging measurements to a remote location so as to enable processing of the data by a digital computer and thereby obtain valuable computed information. Such transmission can be undertaken while the investigating apparatus is being run through the borehole (real time) or at some later time as by recording the measurements on magnetic tape for subsequent transmission.

As is usually the case when such well logging data is transmitted to a remote location, the well logging measurements are converted into digital form for such transmission. To provide a meaningful visual record of such transmitted well logging measurements, it is necessary to produce an analog type of

presentation of the well logging measurements, usually in the form of recorded traces whose positions on a recording medium are representative of the amplitudes well logging measurements versus depth.

When well logging measurements in digital form are transmitted from one location to another, it is sometimes the case that the transmitting tape includes data from two or more magnetic tapes which have been merged on to the transmitting tape. Such merging of data produces a large number of measurement channels on a single tape. (Each channel corresponds to a separate information source). To adequately produce an analog recording of such merged data puts harsh design criteria on a recorder for recording all of this merged data in analog form. To record such merged well logging data as well as unmerged data, in the past, a galvanometer type of recorder has been used. In such a galvanometer recorder a plurality of galvanometer mirrors assume an angular orientation in proportion to the amplitude of the well logging measurement to be recorded such that light reflected off the mirror on to a nearby film will assume the proper position on the film. Unfortunately, a separate galvanometer mirror is required for each and every channel of data to be recorded. While there have been usually, though not always, a sufficient number of recording channels in currently used galvanometer recorders to provide real time recording of well logging measurements (i.e., recording of the measurements as they are derived from the investigating apparatus in the borehole), such is not always the case when recording merged data because of the large number of channels to be recorded.

It is, therefore, an object of the present invention to provide new and improved methods and apparatus for recording well logging data and, more particularly, for recording in a large number of channels of well logging data with one recording device.

According to one aspect of the present

invention, there is provided apparatus for recording or displaying signals of the type representing well logging data as a function of depth, comprising means for directing energy toward a medium, sweep means adapted for sweeping the energy along a line transverse to the medium during successive sweep intervals to place images in the form of dots or linear marks on the medium, timing means for controlling placement of the images in the direction of such line with reference to an initial position, means for producing relative movement between the medium and the line swept by the energy in a direction substantially perpendicular to the line swept by the energy, and means for controlling the level of the energy to regulate the intensity, wherein said timing means provides clock pulses for digitally generating a sweep signal to control the sweep means and a reset signal to determine the sweep duration, and said level control means is responsive to at least the or each data signal and said sweep signal to determine the placement and linear extent of the images and thereby the apparent intensity of lines, traces or patterns to be formed by such images, whereby said lines, traces or patterns are representative of at least the variation of the or each data signal as a function of depth.

According to another aspect of the present invention, there is provided a method of recording or displaying data signals of the type representing well logging data as a function of depth on a recording or displaying medium, comprising the steps of: directing energy towards the medium; generating clock pulses; generating from said clock pulses a sweep signal for periodically sweeping the energy along a line transverse to the medium to place images in the form of dots or linear marks on the medium; timing each sweep of the energy so as to control the placement of the images in the direction of said line with reference to an initial position; generating from said clock pulses a reset signal to determine the duration of each sweep of the energy; producing relative movement between the medium and said line in a direction substantially perpendicular to said line; and varying the level of the energy in dependence on at least the or each data signal and said sweep signal to determine the placement and linear extent of the images and thereby the apparent intensity of lines, traces or patterns to be formed by such images, whereby said lines, traces or patterns are representative of at least the variation of the or each data signal as a function of depth.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, the scope of the

invention being pointed out in the appended claims.

Referring to the drawings:

Figure 1 is a block diagram representation of one embodiment of well logging data recording apparatus constructed in accordance with the present invention;

Figure 1A shows a portion of the Figure 1 system in greater detail;

Figures 2A—2G are waveform diagrams useful in explaining certain features of the Figure 1 system;

Figure 3 illustrates an example of a recording medium on which scale lines have been recorded when utilizing the Figure 1 system;

Figures 4A and 4B show certain portions of the Figure 1 system in greater detail and will hereinafter be referred to simply as Figure 4;

Figures 5A—5K, 6A—6F, and 7A—7F are waveform diagrams useful in explaining the operation of the circuitry of Figure 4;

Figure 8 is an example of a recording medium on which depth lines have been recorded through utilization of the Figure 4 circuitry;

Figure 9 is an example of a recording medium on which both scale lines and depth lines have been recorded;

Figure 10 illustrates a portion of the Figure 1 system in greater detail;

Figures 11A—11E are waveform diagrams useful in explaining the operation of circuitry of Figure 10;

Figure 12 is an example of a log or record produced when utilizing the apparatus of Figure 10;

Figure 13 is a more detailed representation of still another portion of the Figure 1 system;

Figure 14A, 14B and 14C show a more detailed representation of still another portion of the Figure 1 system and will be hereinafter referred to simply as Figure 14.

Figures 15A—15L illustrate examples of recordings produced through utilization of the apparatus of Figure 14;

Figures 16A—16G illustrate waveform diagrams useful in explaining the operation of the apparatus of Figure 14;

Figures 17A and 17B show still other portions of the Figure 1 system in greater detail and will be hereinafter referred to as Figure 17;

Figure 18 shows a well tool in a borehole along with recording apparatus constructed in accordance with the present invention; and

Figure 19 shows still another embodiment of recording apparatus constructed in accordance with the present invention.

Now referring to Figure 1, a digital information source 20 produces output signals which are utilized by the recording apparatus of the present invention to provide recordings of such signals. This information source 20 can take the form of a digital telemetry trans-

mitter receiver such as the system shown in copending application Serial No. 703,427 by Miller et al, filed on February 6, 1968, and granted as U.S. Patent No. 3,599,159 (corresponding to U.K. Patent Specification No. 1,345,581). For present purposes, it will be assumed that the information source 20 takes the form of the digital telemetry system shown in the copending application Serial No. 703,427.

The telemetry system described in this copending Miller et al application is a tape-to-tape synchronous digital transmission system wherein data read from a tape at one remote location is transmitted in serial form to a telemetry receiver at another remote location and written on tape at that remote location. At both the transmitting and receiving locations, the telemetry equipment includes playback circuits which convert the serial digital data to analog output signals which are representative of the digital data. Additionally, this telemetry equipment includes provisions for playing back a tape without transmission to convert the digital data on tape to parallel analog signals. These parallel analog signals are outputted from the telemetry equipment on the conductors 21. The channels 1, 2, 3 n designations on individual ones of these conductors indicates the channel numbers of the data being outputted from the telemetry equipment 20. Each channel corresponds to a different information source or well logging measurement. The outputted data can correspond to transmitted or received data or it can take the form of data played back from a tape without a simultaneous transmission.

These outputted well logging measurements are applied to a plurality of parallel low pass filters 22 which operate to filter out any transients caused by the commutating operation within the telemetry equipment 20. The filtered well logging signals are then applied to a plurality of parallel pulse positions and pulse width modulators 23 which individually operate to produce writing signals for application to subsequent circuits for further processing.

These individual modulators operate to compare a sawtooth sweep signal from a sweep circuit 24 with the individual well logging signals and produce writing signals when the amplitudes of the two compared signals are substantially equal. In producing these writing signals, the individual modulators operate to compensate for variations in the frequency or rate of change of the individual well logging signals. How this is accomplished will be described in detail later.

The modulated signals are then applied to "parallel line coding circuits" 45 where they are selectively coded so that, when recorded on film or the like, the recorded traces for each channel can be readily identified. The

modulated signals are also applied to area coding circuits 48 via an area coding card reader 47. The area coding circuits 48 operate to generate area coding patterns which are recorded between selected traces on the recording medium (e.g., film). The area coding card reader 47 selects the patterns and the signal channels for this coding operation. Both the line and area coded signals are combined in a "combining and logic circuit" 42, as are other signals to be discussed later. The combined signals are applied to a "CRT brightness control circuit" 50 for application to the brightness control grids of the cathode ray tube 25.

The sweep signal generated by the sweep circuit 24 is applied via a "CRT horizontal deflection circuit" 34 to the horizontal sweep coils of the tube 25 for repetitively sweeping the beam across the face of tube 25. The beam is modulated by the signals from the CRT brightness control circuits 50 to record traces on a recording medium (film) 36. Desirably, the cathode ray tube 25 is of the fiber optic type in that it has a fiber optic face plate for bringing about superior resolution of the "spot" (beam striking the face) on the recording medium 36.

The recording medium 36 is moved past the face of the tube 25 at a constant rate by a constant speed motor 37 which moves the film at a rate determined by the transmission rate of telemetry equipment 20. If desired, the motor 35 could be synchronized by the telemetry equipment 20.

Before proceeding with a detailed discussion of how the writing signals are processed for application to a CRT recorder, it would first be desirable to discuss the operation of the sweep circuit 24 portion of the present invention in detail. This sweep circuit 24 operates to periodically generate pulses at a fixed frequency, count these pulses, and produce a sweep signal for application to a cathode ray tube and provide discrete digital signals for use by other circuits in the Figure 1 system.

A pulse generator circuit 26 utilizes the 60 Hertz power line for generating pulses at a frequency of 120 Hertz. (See Figure 2A.) The generator 26 can take the form of an overdriven amplifier, clipping circuit, and monostable multivibrator operating in conjunction to generate a pulse for each zero crossing of the 60 Hertz signal. Each pulse produced by the generator 26 sets a sweep control flip-flop 27 which, when set, enables an AND gate 28 to pass high frequency pulses generated by a high frequency clock 29. (See Figures 2B and 2C.) The pulses from the AND gate 28 designated CL, are divided by two by a flip-flop 30 and applied to the count input of a binary counter 31. As will be seen later, the numerical state of the binary counter 31 corresponds to the position of the beam on the face of a cathode ray tube.

The binary counter 31 output is applied to a binary to analog converter 32 which produces an analog voltage whose magnitude increases in accordance with the increase of the count state of the binary counter 31. Thus, as more and more clock pulses are applied to the counter 31, the output voltage of the binary analog converter 32 will correspondingly increase. This output signal from the converter 32 is designated the "sweep signal" and is shown in Figure 2D. This sweep signal is applied to the modulators 23 as well as to CRT horizontal deflection circuits 34 which process the sweep signal in a manner to produce a linear sweep versus time of the cathode ray tube beam across the face thereof. Thus, the sweep signal can be referred to as a sweep position signal.

An "end of sweep matrix circuit" 35 responds to a selected numerical count of binary counter 31 to produce a reset pulse for resetting the sweep control flip-flop 27. (See Figure 2E.) This sweep reset pulse is also applied to various other circuits in the Figure 1 system for purposes to be described later.

The output signals from each stage of the binary counter 31 are also applied to a scale line circuit 37 which, in response to selected count sequences of the binary counter 31, generates scale line signals used for writing scale lines on the recording medium 36. To accomplish this, the output signals from binary counter 31 are applied to a scale grid card reader 38 which selects certain numerical outputs of the binary counter 31 for application to one of a pair of one-shots 39 and 40. The one-shot 39 produces pulses having a pulse width of time duration t_1 and one-shot 40 produces pulses having a pulse width of time duration $t_1 + t_2$. The output of one-shots 39 and 40 are combined in an OR gate 41 for application to combining and logic circuits 42. Figure 2F shows the resulting scale grid pulses.

The combining and logic circuit 42 processes these pulses from one-shots 39 and 40 to produce scale lines on the recording medium 36. The pulse width of the pulses from one-shots 39 and 40 determine the length of the trace produced on the recording medium 36 as the beam sweeps transversely across the recording medium 36. These traces are shown in Figure 2F. Since the recording medium is moving in a direction perpendicular to the direction of this sweep, the writing time will determine the width of the line produced on the recording medium as the beam is repetitively swept thereacross. The card reader 38 enables any scale line pattern desired to be produced by merely inserting the appropriate card therein.

The scale line circuit 37 also includes an "initial scale line one-shot" 43 which operates in response to the leading or rising edge of

the sweep control signal flip-flop 27 output signal to generate an "initial scale line pulse" for application to the OR gate 41 and separately to the combining circuits 42, as well as to other circuits to be described later. Since, as seen in Figure 2B, the sweep control signal rises at the initiation of the sweep signal of Figure 2D, the one-shot 43 will operate to generate a pulse at the beginning of each sweep, which pulse is used to produce an initial scale line on the recording medium. The reason for this separate treatment of the initial scale line will be described later.

The writing signals from modulators 23 are individually applied to separate ones of a plurality of parallel line coding circuits 45 which operate to code the traces which are recorded on the recording medium 36. As will be explained in more detail later, the coding circuits 45 operate to inhibit selected portions of the writing signals to accomplish this coding operation. The coding circuits 45 also operate in response to the rate of change of the well logging signals to vary the coding operation as a function of this rate of change to enable uniform line coding regardless of the rate of change of the well logging signals. To allow selection of the particular type of coding to be applied to the signals for each channel, the line coding card reader 46 instructs the line coding circuits 45 to apply selected codes to signals from the different channels.

The writing signals from modulator 23 are also applied to an area coding card reader 47 which selects individual ones of the writing signals from modulators 23 for application to individual coding circuits of the area coding circuits 48. The area coding circuits 48 include a plurality of pattern generators which operate to individually produce any one of twelve patterns on the recording medium 36. Examples of these patterns are shown in Figures 15A—15L. These patterns can indicate such subsurface constituents as oil, gas, sand, porosity, water, limestone, etc.

As discussed earlier, it is usually the case that the area between two recorded traces indicates the amount of a particular subsurface constituent only when one of the traces is on one or the other side of the other trace on the recording medium. To enable the area coding circuits 48 to generate patterns only under the proper conditions, the area coding card reader 47 causes the card reader 47 to select certain ones of the writing signals as "start" signals and certain ones as "stop" signals. The start signals will signal the circuits 48 to begin producing the area coding pattern and the stop signals will cause the pattern to terminate. If the selected start-stop signals are reversed, no pattern will be produced.

Additionally, the line coded writing signals are applied to a "trace intensifier card reader"

49 which, in response to a selected card placed therein, selects certain ones of the line coded writing signals for application to a special input channel of the combining and logic circuit 42. The circuit 42 operates to boost the amplitude of these selected signals to hereby intensify the recorded trace for just these signals. The combining circuits 42, among other things, combines all of the line coded and area coded signals and separately combines the trace intensified signals for all channels for application to the CRT brightness control circuits 50. The combining circuits 42, in addition to combining these signals, also includes suitable logic circuits which operate to give preferential treatment to certain ones of the writing signals applied thereto for purposes to be explained later.

The CRT brightness control circuits operate to combine the line and area coded writing signals, the trace intensified signals and scale line signals (as well as depth line signals—to be discussed later) and produce signals for modulating a grid of the cathode ray tube 25. The brightness control circuits 50 also operate to monitor and control the beam current produced by the cathode ray tube 25.

As discussed earlier, the cathode ray tube is modulated by the writing signals produced from well logging measurements at random time intervals, thus making it very difficult to properly monitor the beam current for control purposes. To circumvent this problem, in accordance with an important feature of the present invention, the initial scale line pulse from scale line circuit 37 causes the cathode ray tube beam to be unblanked a specified amount and at a specified time period during each sweep. This specified time is the beginning of each sweep. To this end, the initial scale line pulse from the scale line circuit 37 is applied to the CRT brightness control circuits 50 to inform the circuits as to the time when the initial scale line is being written. As will be explained in greater detail later, the CRT brightness control circuits 50 operate in response to this initial scale line pulse to sample the beam current and appropriately adjust it, if necessary. By so doing, the beam current will be maintained at the desired level.

The system of Figure 1 also operates in accordance with other features of the present invention to record depth information, e.g., depth lines and depth numbers on the recording medium 36. To accomplish this, the initial depth at which well logging measurements are derived is set into depth determination circuits 60 by a plurality of initial depth preset switches 61. Data from the telemetry transmitter or receiver is thereafter utilized to continuously update the depth determination circuits 60. The depth determination circuits 60 continually provides data for a depth display unit 62 so that a numeri-

cal representation of the depth of the well logging signals outputted from the telemetry transmitter or receiver 20 can be viewed at all times.

To update the depth determination circuit 60, pulse code modulated data from the telemetry unit 20 is applied to the depth determination circuit 60 for entry into an appropriate register. The telemetry equipment 20 also supplies shift pulses and a shift pulse window to the depth determination 60 to enable the pulse code modulation data to be shifted into the register at only the time period when a depth word is being transmitted or received. The shift pulses are applied to this entry register under control of the shift pulse window, the shift pulse window acting to insure that only the necessary number of shift pulses are actually applied to this entry register. The telemetry equipment 20 causes a depth shift command pulse to be applied to the depth determination circuits 60 to insure that only depth words are entered into this entry register. The depth data in this entry register is then shifted to another register by a gate control pulse from the telemetry equipment 20 after the depth word has been entered into this entry register. How the depth determination circuits 60 utilize these signals from the telemetry equipment 20 will be described in detail later.

As mentioned earlier, the telemetry equipment 20 is described in copending Miller et al application Serial No. 703,427. In this copending application, the pulse code modulated data is derived from the wiper arm of a four position switch 70A in Figure 15C of that application. The shift pulses are derived from the output of an AND gate 205 in Figure 15A of the copending Miller et al application and are designated "shift 14" therein. The shift pulse window is derived from a one-shot 187 in Figure 15A of the copending Miller et al application and is designated "tape write and depth display window" therein. The depth shift command pulse is derived from the wiper arm of a four position switch 70E in Figure 15A of the copending Miller et al application and is designated "command shift depth display" therein. The gate control pulse is derived from a one-shot 188 in Figure 15A of the copending Miller et al application and is designated "X₄" therein.

It is to be understood that the telemetry apparatus for producing these above-described signals does not comprise part of the present invention. Furthermore, it is to be understood that any information source could be utilized as the input to the recording apparatus of the present invention and the invention is thus not limited to recording data from the telemetry equipment described in the copending Miller et al application.

The depth determination circuits 60 supply

data to a depth interval detector 63 which operates to generate signals representative of 2', 10', 50' and 100' depth intervals. The 2', 10' and 50' depth interval signals are applied to a "depth line generator" 64 which operates to generate "depth line writing signals" for application to the combining and logic circuits 42 for subsequent recording. The depth line generator 64 operates to generate one line for every 2 foot depth interval, two lines for every 10 foot interval and four lines for every 50 foot interval. The depth determination circuit 60 also supplies data to a "digit selector circuit" 65 which processes the depth data and causes a numerical display of the depth number by energizing a cathode ray tube numerical display unit 67 via a "depth driving CRT circuit" 66. The display unit 67 is positioned relative to the recording medium 36 so as to record numerical representations of the depth numbers on the recording medium 36. The digit selector circuits 65 process the depth data from the depth determination circuits 60 so that depth numbers will be printed on the recording medium 36 when the last two digits of the depth numbers are 96, 98, 00, 02, and 04. Thus, for example, a digit of a depth number will be recorded at each of 2196 ft., 2198 ft., 2200 ft., 2202 ft., and 2204 ft. By so doing, the depth number will appear sideways on the record medium to minimize the width of the depth track.

The hundred foot depth interval signals from the depth interval detector 63 are applied to a sawtooth generator 70 which operates to generate a timing signal having a time period corresponding to 100 feet of data generated from the telemetry equipment 20. This 100 ft. sawtooth signal is applied to a vertical deflection amplifier 71 which drives the vertical deflection coil of a storage cathode ray tube 72. The horizontal sweep signal from the sweep circuit 24 is utilized to energize the horizontal sweep coil of the storage cathode ray tube 72 via a horizontal deflection amplifier 73. The CRT brightness control circuits 50 supply the combined writing signals to the storage cathode ray tube 72 to modulate the beam intensity thereof.

By this arrangement, in accordance with another feature of the present invention, the storage cathode ray tube 72 will provide a visual display of up to 100 feet of recorded data to thereby enable one to visually determine what data has been recorded on the recording medium 36. The phosphor of the storage CRT 72 is erased at the end of each 100 ft. interval.

Now turning to Figure 4, there is shown the depth determination circuits, initial depth preset switches, digit selector circuits, depth interval detector and depth line generator of Figure 1 in greater detail. First, concerning the initial depth preset switches 61, five

decade switch 80, 81, 82, 83 and 84 are set in accordance with the initial depth of the data which is being transmitted or received by the telemetry equipment 20. The decade switch 80 corresponds to units of feet, the decade switch 81 to tens of feet, switch 82 to hundreds of feet, switch 83 to thousands of feet, and the switch 84 to tens of thousands of feet. The ten contacts of each decade switch are connected to individual decimal to binary coded decimal converters 85 which operate to convert the decimal number from each decade switch to a binary coded decimal number.

The binary coded decimal numbers corresponding to the tens, hundreds, and thousands foot switches are applied to the tens, hundreds and thousands foot positions of a five decade depth memory register 86 via OR gates 87. The units and tens of thousands foot binary coded decimal numbers are applied directly to the corresponding portions of the register 86.

To set the initial depth number into the register 86, a switch 87 is momentarily depressed so as to apply a DC voltage to the wiper arms of the five decade switches 80-84. Once the switch 87 is depressed, the memory register 86 will have stored therein the initial depth of the measurements to be received from the telemetry equipment 20.

The depth memory register 86 is then continually updated as data is transmitted, received or played back by the telemetry equipment 20. To accomplish this, the pulse code modulated data from the telemetry equipment 20 is entered into a three-decade shift register 90. As discussed in the copending Miller et al application Serial No. 703,427, depth words are transmitted every ten feet. Thus, whenever a depth word is entered into the depth register 90, it can be assumed that the lowest order digit will always be zero.

Since the PCM data conductor from telemetry equipment 20 has data therein continuously, the depth entry register 90 is activated only when a depth word is being transmitted or received. To accomplish this, the shift pulses and shift pulse window (which corresponds in time to the generation of the shift pulses) and the depth shift command pulse from the telemetry equipment 20 are combined in an AND gate 91. The resulting gated shift pulses from AND gate 91 are utilized to shift the contents of the depth register 90 only when depth words are being transmitted, received, or played back. By this means, only depth words will be entered into the depth register 90.

After depth has been entered into the register 90, a plurality of depth memory control gates 92 are energized by the gate control pulse from the telemetry equipment 20 to transfer the data in the depth register 90

to the tens, hundreds, and thousands foot portions of the depth memory register 86 via the OR gates 87. Thus, the tens, hundreds and thousands portion of the memory register 86 will be continuously updated while data is processed by the telemetry equipment 20.

To update the units foot portion of the depth memory register 86, the shift pulse window pulses from the telemetry equipment 20 are divided by two by a flip-flop 93 and then applied to the count input of the unit foot position of the register 86. As discussed in the copending Miller et al application Serial No. 703,427, the shift pulse window pulses are generated once per six inches of depth. Thus, the units foot portion of the depth memory register 86 will be updated at one foot intervals. The register 86 counts down to correspond with the telemetry operation. (Boreholes are logged from bottom to top and thus the actual depth footage decreases.)

The contents of the depth memory register 86 are applied in parallel fashion to the depth display unit 62 such that a visual numerical display of the depth of the data being transmitted, received or played back by the telemetry equipment 20 can be obtained at all times. The contents of the depth memory register 86 are also applied to the digit selector circuits 65, which as discussed earlier, operate to select those depth numbers whose last two digits are 96, 98, 00, 02, and 04 for application to the cathode ray tube numerical display device 67.

To accomplish this, the binary coded decimal output signals from the units and tens decade units of the depth memory register 86 are applied to a pair of binary coded decimal to decimal converters 95 and 96 respectively. The count sequences for the combination of converters 95 and 96 are shown in Figure 5A. An AND gate 97 is responsive to the zero digit of the converter 96 and the No. 4 digit of the converter 95 for producing the pulse of Figure 5B for setting a flip-flop 98. When set, the flip-flop 98, whose normal output is shown in Figure 5C, enables an AND gate 99 to pass a two foot depth signal from the depth interval detectors 63. The gated two foot depth signal is shown in Figure 5D. (This two foot depth signal is obtained by dividing the one foot depth signal from the flip-flop 93 by two with a divide by two flip-flop 100 within the depth interval detector 63.) Every two feet the leading edge of the gated two foot signal from AND gate 99 advances a binary counter 101 and energizes a one shot 102. The binary counter 101 count sequences are shown in Figure 5E and the one shot 102 output pulses are shown in Figure 5G.

The three stages of the binary counter 101 are connected to a binary to decimal converter

103 which produces an output signal on one of five output conductors during the first five count sequences of the binary counter 101.

As stated earlier, depth numbers are printed on the record medium 36 sequentially in reverse order as the record medium moves past the depth number printing CRT 67 (see Figure 1) and since depth numbers are printed every 100 feet, the first two printed digits will be zero. Thus, the first and second output sequences from converter 103 are combined in an OR gate 112 and applied to the zero input position of the CRT numerical display unit 67 via an AND gate 113. The AND gate 113 is enabled by the output pulse from one-shot 102 to cause the CRT 67 to be flashed at the proper time and for the proper time duration to enable an appropriate exposure time on the film record medium 36.

The hundreds, thousands, and ten thousands binary coded decimal signals from the depth memory register 86 are applied to three parallel binary coded decimal to decimal converters 104. The conjunctive combination of the third sequence output signal from the binary decimal to decimal converter 103 and the pulse from the one-shot 102 energizes ten individual parallel gates 105 by way of an AND gate 106. When energized, the gates 105 connect the ten output conductors from the hundreds foot portion of the binary coded decimal to decimal converter 104 to ten OR gates 107. The enabling pulse from AND gate 106 is shown in Figure 5H.

The number 4 sequence output from the binary to decimal converter 103 and the pulse from one-shot 102 are combined in an AND gate 107 for energizing 10 parallel gate circuits 108. When energized, the parallel AND gates 108 connect the ten output conductors from the thousands foot portion of the binary coded decimal to decimal converter 104 to individual ones of the OR gates 107. The enabling pulse from AND gate 107 is shown in Figure 5I.

In like fashion, the No. 5 sequence output from the binary to decimal converter 103 is combined with the output pulses from one-shot 102 in an AND gate 109 for energizing the parallel AND gates 110 during the fifth sequence of the binary counter 101. (See Figure 5K.) When energized, the parallel AND gates 110 connect the ten output conductors from the ten thousands foot portion of the binary coded decimal to decimal converter 104 to individual ones of the OR gates 107. The outputs from the 10 OR gates 107 are connected to individual ones of the ten input terminals of the CRT numerical display unit 67. The leading edge of the No. 5 sequence output signal resets the flip-flop 98 and thus the AND gate 99 to prevent the counter 101 from being advanced beyond sequence No. 5.

To reset the binary counter 101, an AND gate 111 is responsive to the No. 2 output of the units foot position of the binary coded decimal to decimal converter 95 and the nine digit output of the tens foot output position of the binary coded decimal to decimal converter 96 for resetting the binary counter 101 whenever the tens and units digits of the depth number are 92.

Summarizing the operation of the digit selector circuit 65, whenever the last two digits of the depth number are 04 as determined by the AND gate 97, the flip-flop 98 is set to enable binary counter 101 to count the rising edges of the two foot depth signal from the depth interval detector 63, as seen by inspecting Figures 5A—5D. As seen in Figure 5E, the binary counter 101 counts five rising edges of the two foot depth signal and then resets itself when the last two digits of the depth number are 92.

During the first two sequences, the binary to decimal converter 103 energizes the "zero" input of the numerical display unit 67 by way of the OR gate 111. During the third sequence, i.e., at a depth whose last two digits are 00, the number for the hundreds foot digit is gated by the parallel gates 105 to the proper input terminal of the numerical display unit 67 by way of the OR gates 107. Thus, for example, if the hundredths foot number is 6, the numerical display unit 67 will display the number 6 during sequence 3. During sequences 4 and 5 the thousandths and ten-thousandths foot numbers are likewise gated to the proper input terminals of the numerical display unit 67.

At the beginning of sequence 5, the flip-flop 98 is reset to thereby disable advancement of the binary counter 101. The binary counter 101 is then reset after the entire number has been printed by the pulse from AND gate 111.

Taking an example of this operation assume that the number to be printed is 5100 feet. At 5104 feet, the flip-flop 98 will be set and the binary counter 101 will advance to its first count sequence, thus enabling the AND gate 113 via OR gate 112. The pulse from one shot 102 then energizes the zero digit of the display unit 67 and a zero is printed at 5104 feet. Next, at 5102 feet the binary counter 101 advances to its number two count sequence and through the same operation a zero is again printed. At 5100 feet the binary counter 101 advances to its number three count sequence, thus enabling the AND gate 106 to pass the pulse from one shot 102 to the parallel gates 105. The hundredths foot portion of binary coded decimal to decimal converter 104 will, at this time, be generating an output signal on the number five output conductor such that when the gates 105 are energized, the number five digit of the display unit 67 will be energized. Then at the

number four sequence, the number five output signal from the thousandths foot portion of converter 104 will energize the number five digit of the display unit 67. During the fifth sequence, the zero digit of the display unit 67 will be flashed. Then at 5092 feet, a safe time after the entire depth number has been printed, the system will be reset in readiness for the same operation to occur at 5004 feet for printing the depth number 5000.

Now concerning the depth interval detector 63, it operates in response to data from the depth register 90 and the divide by two flip-flop 93 to generate 2, 10, 50 and 100 foot signals. How the two foot signal is generated has already been discussed. To generate the 50 foot signal, a matrix circuit 120 is responsive to the tens foot portion of the depth register 90 to generate an output pulse every 50 feet. To generate the 100 foot signal, a matrix circuit 121 is responsive to the hundreds foot portion of the depth register 90 to generate a pulse every 100 feet. The ten foot depth pulses are obtained directly from the depth shift command output of the telemetry equipment 20 since, as discussed earlier, a depth word is transmitted every ten feet by the telemetry equipment described in the copending Miller et al application.

The hundreds foot depth pulses from the detector 63 are applied to the hundred foot sawtooth generator 70 of Figure 1 to enable the hundred foot depth sweep for the storage cathode ray tube 72.

The depth line generator 64 operates in response to the 2, 10, and 50 foot depth signals from the depth interval detector 63 to generate signals which causes a line to be written on the recording medium every two feet, two lines to be written every ten feet, and four lines to be written every fifty feet. To accomplish this, referring to Figures 4 and 6A—6F in conjunction, and first concerning the two foot portion of the depth line generator 64, the leading edges of the two foot depth signals, shown in Figure 6A, set a flip-flop 125 which, when set, enables an AND gate 126. The normal output of flip-flop 125 is shown in Figure 6C. When enabled, the AND gate 126 passes the sweep reset pulses, shown in Figure 6B, to the set input of a flip-flop 127. The resulting gated sweep reset pulses are shown in Figure 6D. The flip-flop 127 is set on the trailing or falling edge of each gated sweep reset pulse of Figure 6D. The trailing edge of each sweep reset pulse also resets the flip-flop 125 via an inverter constituted by a suitably converted NAND gate 128 which inverts the output pulses from AND gate 126 to enable the pulse rising edges to reset flip-flop 125.

The normal output of flip-flop 127, shown in Figure 6E, is applied to an OR gate 130. The output signals from OR gate 130 con-

70

75

80

85

90

95

100

105

110

115

120

125

130

stitute the depth line signals which are applied to combining and logic circuit 42 for eventually causing one line to be swept transversely across the recording medium 25 every two feet. To insure that only one depth line is printed every two feet, the normal output of the flip-flop 127 enables NAND gate 131 to pass the sweep reset pulses to the reset input of the flip-flop 127 after one sweep of a depth line has been completed. The output signals from NAND gate 131 is shown in Figure 6F.

To generate two such depth lines every ten feet is the function of the ten foot depth line generator 133 of the depth line generator circuitry 64. The ten foot depth line generator 133 operates in an identical fashion as the two foot depth line generator 124 except that a divide by two flip-flop 134 prevents the control flip-flop corresponding to flip-flop 127 of the two foot circuit 124 from being reset until two sweeps have been completed and the two depth line sweeps are initiated by the ten foot signal from depth interval detector 63. Thus, during the time that it takes the cathode ray tube 25 to complete two sweeps, the output of the OR gate 130 is maintained at the "one" level by the ten foot line generator 133 to thereby produce two depth lines on the record medium every ten feet.

To generate four depth lines every 50 feet, a 50 foot depth line generator 135 responds to the fifty foot depth pulses from the depth interval detector 63. The fifty foot depth line generator 135 operates in an identical fashion with the two foot and ten foot depth line generators 124 and 133 except that a divide by four circuit 136 prevents the system from resetting itself until four sweeps have been completed. These elements in the 10 foot and 50 foot depth line generators 133 and 135 which are identical in operation with elements in the two foot depth line generator 124 are designated the same except for the addition of a letter A after the numbers for the ten foot depth line generator 133 and the addition of a letter B for the fifty foot depth line generator 135.

Figure 8 is an example of a recording medium with the depth lines printed thereon through utilization of the depth line generator circuit 64. In Figure 8 it can be seen that the depth lines at 10 foot intervals are wider than the depth lines at 2 foot intervals and that depth lines at 50 foot intervals are wider and thus more outstanding in appearance than either the two foot or 10 foot interval depth lines.

Now, turning to Figure 9, there is shown a recording medium on which both depth and scale lines have been printed, as well as the depth numbers. In addition to the distinguishing features of the 2, 10 and 50 foot depth lines, it can be seen that one of the

scale lines per track is darker than the rest. This is accomplished by inserting the desired card into the scale grid card reader 38 of Figure 1. The depth tack is shown in Figure 9 as being located between tracks 1 and 2 and devoid of any printing other than the depth number. To accomplish this, the scale grid card reader generates a signal designated "Depth Track Inhibit" (the means "NOT Depth Track Inhibit") which is utilized by the combining and logic circuit 42 to inhibit scale and depth lines from being printed in the depth track (see Figure 1).

A depth number 11300 is printed in the depth track. It can be seen that there is one digit of this number printed every two feet for a ten foot interval. At 1304 and 1302 feet "zeros" are printed and at 1300, 1298 and 1296 feet the digits 311 are printed such that when examining the recording medium, it is evident that the heavy depth corresponds to a depth of 11300 feet.

As discussed earlier, a trace is recorded on the recording medium 25 by periodically sweeping the cathode ray tube beam transversely across the recording medium and unblanking this beam at the proper time. If the well logging signal to be recorded has a slow rate of change, the marks will be placed on a recording medium in relatively closely spaced apart positions. If the signal to be recorded has a fast rate of change, these marks will be placed on a recording medium at relatively widely spaced apart positions. This difference is undesirable since it presents a non-uniform log. To alleviate this problem each pulse position and pulse width modulators 23 individually operate to vary the width of the trace recorded on the recording medium in accordance with the rate of change of the signal to be recorded.

To this end, referring to Figure 10, there is shown one of the pulse position and pulse width modulators. In actuality there are as many modulators as there are signal channels but since all such modulators are identical, it is only necessary to show one here. In Figure 10, the channel signal from one of the low pass filters 22 (in this case, the channel n signal is used) is applied to a voltage comparator 140 where it is compared in amplitude with the sweep signal from the sweep circuit 24. When the amplitude of the sweep signal exceeds the channel n signal amplitude, the voltage comparator 140 changes from the "zero" to "one" state.

The channel n signal is also applied to a second voltage comparator 141 after being delayed by a delay circuit 142. The voltage comparator 141 also compares the channel signal with the sweep signal to generate a "one" upon the sweep signal amplitude exceeding the channel signal amplitude.

The outputs of both voltage comparators 140 and 141 are applied to the input of an

70

75

80

85

90

95

100

105

110

115

120

125

130

Exclusive OR gate 143 which changes from the "zero" to "one" state when one, but not both, outputs of the voltage comparators 140 and 141 are at the "one" level. The trailing edge of the resulting output pulse from the Exclusive OR gate 143 energizes a one-shot 144 and the output pulses from the exclusive OR gate 143 and one-shot 144 are ORed together in an OR gate 145 to produce the "writing signal" for application to the line coding circuit 45 (see Figure 1). The output signals from the voltage comparators 140 and 141 are also ORed together in an OR gate 146 for application to the area coding card reader 47 for purposes to be explained later.

Concerning the operation of the Figure 10 modulator and referring to Figures 11A—11E, Figure 11A shows the sweep position signal and delayed and undelayed channel signals, the delayed channel signal being shown in dashed line form. Figure 11B shows the output pulses from the exclusive OR gate 143 and Figure 11D shows the output pulses from the OR gate 145. The resulting recording trace is shown in Figure 11E.

By comparison of Figures 11A and 11B it can be seen that the pulse width of the output pulses from the Exclusive OR gate 143 will vary as a function of the rate of change of the channel signal to be recorded. Thus, as illustrated by the left-hand portion of Figures 11A and 11B, these pulse widths will be extremely narrow when the input channel signal does not vary in amplitude.

As seen by the intermediate portion of Figures 11A, when the channel signal begins to change in amplitude, the delayed channel signal will have the same change but at a delayed time. This causes the sweep signal to define a given time interval between the delayed and undelayed channel signals which defines the pulse width of the pulses of Figure 11B. At the right-hand side of Figure 11A, the input channel signal changes amplitude very rapidly, thus causing the sweep signal to define a long time interval between the time when the sweep signal amplitude equals the channel signal to the time when it equals the delay channel signal.

Thus, it can be seen that the faster the rate of change of the channel signal, the longer will be the duration of the output pulse from the Exclusive OR gate 143. The one shot 144 acts to guarantee a minimum pulse width for the modulator output pulses such that minimum pulse width pulses will be generated when DC signals are being recorded. The combined output pulses from the exclusive OR gate 143 and one-shot 144 are shown in Figure 11D and produce the recording traces of Figure 11E.

Referring to Figure 12, there is shown an example of a recording made using the modulator of Figure 10. During the period when the channel signal does not vary in amplitude,

it can be seen from Figure 12 that dots will be recorded on the recording medium. However, when the amplitude of the signal begins changing, the transverse sweep lengths become longer, thus compensating for the increase in the rate of change of the input channel signal. The overall result is to produce a recording which is uniform in appearance regardless of the rate of change of the input channel signal.

Now, referring to Figure 13 there is shown one of the parallel line coding circuits 45 of Figure 1 in detail. Since all of the line coding circuits are identical, it is only necessary to show one circuit in detail. The function of the line coding circuits is to code the line which is recorded on the recording medium 36 to thereby enable easy identification of each of the various signals being recorded. Each line coding circuit receives an instruction from the line coding card reader 46 to produce a dotted, dashed, long dashed, or solid line on the recording medium.

One way of accomplishing this is to register a count for each sweep of the CRT beam and alternately blank and unblank the writing operation for a specified number of such sweep counts to produce the desired code. To this end, the sweep reset pulses from the sweep circuit 24 of Figure 1 are applied to an OR gate 150 which, after processing by some logic circuits are applied to a divider made up of a divide by five counter 151 and a divide by eight counter 152.

To this end, the sweep reset pulses from the sweep circuit 24 of Figure 1 are applied to an OR gate 150 which, after processing by some logic circuits, are applied to a divider made up of a divide by five counter 151 and a divide by eight counter 152. The feedback connections for the counters 151 and 152 are selectable to produce the desired line coding pattern. Thus, for example, a mark could be recorded for 40 sweeps and inhibited for 40 sweeps, or recorded for 160 sweeps and inhibited for 40 sweeps, etc. To perform the recording and inhibit function, the normal output of the last stage of the divide by eight counter 152 enables an AND gate 158 to pass the writing signal from the appropriate one of modulators 23 to the combining and logic circuit 42.

As discussed earlier, the length of the dots or dashes will be dependent on the rate of change of the channel signal to be recorded. In other words, if a dotting pattern is desired where marks are inhibited from being placed on the recording medium for 40 sweeps and then recorded for 40 sweeps, it can be seen that 40 sweeps for a DC signal will produce a much shorter line on the recording medium than 40 sweeps for a rapidly varying signal.

To provide a uniform line coding pattern regardless of the rate of change of the input channel signal, the writing signal from the

proper modulator 23 enables an AND gate 153 which, when enabled, passes high frequency clock pulses from a clock source 154 to the other input of the OR gate 150. Thus, when the channel signal has a high rate of change, more pulses are applied to the counters 151 and 152 than for the case of a slowly varying signal. The frequency of the clock source 154 is chosen in accordance with the CRT beam sweep rate to produce the desired results.

Now, concerning how each of the individual line coding patterns are produced and first concerning the dotting pattern, the output pulses from OR gate 150 are applied to one input of an AND gate 155 and one input of an AND gate 156. The normal output of the last stage of the divide by eight counter 152 and the dotting control signal from the line coding card reader 46 enable the AND gate 156 to pass the pulses from the OR gate 150 to the count input of the divide by five counter 151 via an OR gate 157. Thus, when the line coding circuit is in the dotting mode and the normal output of the last stage of the counter 152 is at the "one" level, the counters 151 and 152 will, in conjunction, proceed to count 40 pulses from the OR gate 150. At the end of 40 pulses, the last stage of the counter 152 changes to its complementary state, thus disabling the output AND gate 158 and enabling the AND gate 155 to apply pulses to the input of the counter 151 via the OR gate 157. After 40 more pulses have been counted, the normal output of the last stage of counter 152 returns to the "one" state, thus enabling the AND gate 158 to pass writing signals to the combining and logic circuits 42 of Figure 1 and enabling the AND gate 160 again. The process then repeats itself.

Thus, it can be seen that the line coding circuit of Figure 13 will inhibit at least a selected portion of one writing signal from passing to the combining and logic circuits 42. As a maximum, it could inhibit many writing signals. The criteria for inhibiting the writing signals or portions thereof is not the number of writing signals themselves but the length of the line being recorded on recording medium 36. This length is a function of the pulse width of the writing signals from modulator 23. Thus, the AND gate 153 will gate a quantity of clock pulses to the counters 151 and 152 per sweep depending on the rate of change of the channel signal. The application of the sweep reset signal to the OR gate 150 for counting by counters 151 and 152 serves to set a minimum limit of one count per sweep when a DC signal is being recorded. Looking at the extremes, if the channel signal has a low rate of change, a great many writing signals would be inhibited and if it has a high rate of change, a portion of one writing signal would be

inhibited or if the rate of change is very high, several non-adjacent portions of one writing signal could be inhibited.

The dashing and long dashing operations are very similar to the dotting operation except that the waveform generated by the counter 152 will be unsymmetrical. This unsymmetrical waveform is produced by inserting a divide by four counter 159 in the feedback path from the normal output of the last stage of counter 152 to the input of the counters 151 and 152. Thus, during a dashing operation, an AND gate 160 is enabled such that when the normal output of the last stage of counter 152 goes to the "one" level, the pulses from OR gate 150 will be applied to the divide by four counter 159. By so doing, the absence of a recorded trace will be 1/4 the length of the recorded traces on the record medium 36. To provide a long dashing operation, a divide by eight counter 161 is inserted in the feedback path. Thus, during such a long dashing operation, an AND gate 162 is enabled such that when the normal output of the counter 152 is at the "one" level, counters 161, 151 and 152 operate in a serial fashion to count pulses from the OR gate 150. This arrangement dictates that the recorded traces will be eight times as long as the absence of such traces thus giving a long dashed line.

To produce a solid line on the recorded medium 36, a control signal designated "solid" from the line coding card reader 46 sets the last stage of the counter 152 to its normal state such that the AND gate 158 is always enabled to pass writing signals.

Now referring to Figure 14, there is shown the area coding circuits 48 of Figure 1 in greater detail. The area coding circuits of Figure 14 are made up of twelve individual pattern generators which are utilized to generate the patterns shown in Figures 15A-15L. As discussed earlier, these coding patterns are generated whenever a selected channel signal assumes a predetermined relationship to a second channel signal. The area coding card reader 47 selects certain ones of the pulses generated by the OR gate 146 (see Figure 10) of each modulator of the parallel position and pulse width modulators 23 as "start" signals (start coding) and certain ones as "stop" signals. The area coding card reader 47 also selects certain ones of the divided clock signals from the binary counter 31 for application to the area coding circuits. In Figure 14, these signals are designated SC2, SC4, SC8, etc., with the number following "SC" indicating the stage of the counter 31, i.e., SC2 indicates that the second stage of the counter 31 has been selected.

The first circuit to be described will produce the area coding pattern shown in Figure 15A. This pattern usually designates oil. In Figure 14, a divide by four counter 171

counts the trailing or rising edges of inverted 60

sweep reset pulses, designated $\overline{SR}$, produced by inverting the sweep reset pulses from the sweep circuit 24 of Figure 1. The falling edges of the square wave output signal from the divide by four flip-flop 171 and the

inverted sweep reset pulses $\overline{SR}$ from the AND gate 172 energize the set and reset inputs respectively of a flip-flop 173. The rising edges of the output signal from the normal output contact of the flip-flop 173 toggle a flip-flop 174 which, when the normal output of flip-flop 173 is at the "one" level, enable a pair of AND gates 175 and 176 respectively to pass the sweep counter signals $\overline{SC2}$ and

$\overline{SC2}$ respectively to a "trace length one-shot" 177. The pulse width of the pulse generated by the one shot 177 is set such as to produce the desired trace length or the recording medium, i.e., it determines the unblanking time of the cathode ray tube 25.

To insure that the oil coding pattern is printed only when one selected channel signal has a predetermined relationship with the other selected channel signal, the trace length pulses from one shot 177 are combined in an AND gate 178 with the start and stop signals from the area coding card reader 47. The card reader 47 provides for inversion of the stop signals.

The card reader 47 selects those area coding control signals which are utilized as the start

and stop signals for each of the pattern generators of Figure 14. Thus, for example, if the oil coding pattern generated by the circuit 170 is to be printed on a recording medium whenever the channel 2 signal is greater in amplitude than the channel 4 signal, the card reader 47 will select the channel 4

signal as the stop signal and apply these to the oil coding circuit 170. To insure that no scale and depth lines are recorded while the area coding pattern is being recorded, the

start and stop signals from the area coding card reader 47 are combined in an AND gate 179 to produce a control signal representative of the time interval during which the area coding pattern is being generated. This area coding blanking signal is applied to the combining and logic circuit 42, which as will be discussed later, blanks out depth and scale lines while the area coding pattern is being recorded.

To better understand how this conditional area coding operation takes place refer to the oil coding circuit 17 of Figure 14 in conjunction with Figures 16A—16F. Figure 16A is an illustration of the sweep signal overlaid on the channel signals which are selec-

ted by the area coding card reader 47 as the start and stop signals for use by the area coding circuits. Figure 16B shows the sweep reset pulses generated by the sweep circuit 24 of Figure 1.

It will be recalled from the discussion of the modulator of Figure 10 that the output of the OR gate 146 will rise to the "one" level upon the sweep voltage exceeding the channel signal amplitude and will remain at that level until the sweep signal amplitude is less than the channel signal amplitude. Thus the area coding control signal generated by the modulator which is processing the signal designated "start" in Figure 16A will produce the area coding control signal of Figure 16C. Likewise, the modulator which is processing the channel signal designated "stop" in Figure 16A will produce an inverted version of the area coding control signal

shown in Figure 16D. (The stop signal is illustrated in Figure 16D.) Through action of the area coding card reader 47, the signal in Figure 16C becomes the start signal and the control signal of Figure 16D becomes the

stop signal which are applied to the AND gates 178 and 179.

The conjunctive function, start-stop is shown in Figure 16E and, through the action of AND gate 179, comprises the area coding blanking signal. Likewise, through the action

of AND gate 178, start and stop enables the area coding signal pulses from the trace length one-shot, shown in Figure 16F, to be applied to the combining and logic circuit 42 as the area coding writing signal whenever the normal output of the flip-flop 173, shown in Figure 16G, is at the "one" level. Since the flip-flop 173 is set only once every four sweeps, after the sweep reset pulse 180 of Figure 16B resets flip-flop 173 (see Figure 16G), this flip-flop will remain in a reset state for the next four sweeps. Then it will be set by the fourth reset sweep pulse after pulse 180 to allow the area coding signal of Figure 16F to be passed.

It can, therefore, be seen that the oil coding circuit 170 will operate to produce evenly spaced dots on the recording medium 36 for one out of every four sweeps in the area bounded by the logs selected by the area coding card reader as the start and stop logs. The space between each dot in the direction of the sweeping beam (transverse to the record medium 36) will be determined by the counter signal $\overline{SC2}$. The toggle FF 174 changes state, every fourth sweep, and alternately enables gates 175 and 176, thus alternately connecting $\overline{SC2}$ and $\overline{SC2}$ counter sig-

nals to the one-shot 177. This staggers the dots printed on alternate lines of dots.

Now, concerning the circuit for producing a coding pattern which designates "gas", refer to the "gas coding circuit" 182 of Figure 14. This gas coding circuit 182 operates in a manner very similar to the oil coding circuit 170 except that only one sweep out of eight is utilized to produce dots on the recording mediums and these dots are spaced twice as far apart as those for the oil coding circuit 170.

The major portion of the gas coding circuit 182 is the logic circuit A portion of the oil coding circuit 170. In circuit 170, this logic circuit A comprises all of the oil coding circuit 170 except the divide by four circuit 171 and is that portion of the oil coding circuitry enclosed by the dashed lines.

To produce the recording of dots once every eight sweeps, the square wave output signal from the divide by four flip-flop 171 of circuit 170 is applied to a divide by two flip-flop 183. The output of the divide by

two flip-flop 183 is thus equal to $\overline{SR}/8$ and is applied to the set input of the corresponding flip-flop 173 within the logic circuit A of the gas coding circuit 182. To produce the wider spacing of dots during those sweeps

when dots are recorded, the SC4 and SC4 signals from the binary counter 31 of Figure 1 are applied to AND gates within the logic circuit A of the gas coding circuit 182 which correspond with the AND gates 175 and 176 of the oil coding circuit 170. The resulting pattern produced on the recording medium is illustrated in Figure 15B.

Looking now at Figure 15C, there is shown the area coding pattern used to designate "sand". It can be seen that the dots recorded for this pattern are further spaced apart than the dots for the pattern shown in either Figures 15A or 15B. Returning to Figure 14, the "sand logic circuit" 185 acts to produce this coding pattern of Figure 15C. The sand logic circuit includes the logic circuit A discussed earlier. To produce the wider spaced

dots, the $\overline{SR}/8$ square wave signal from the flip-flop 183 is applied to a divide by two flip-flop 186 within the sand logic circuit 185 so that the dots will be recorded only once every sixteen sweeps. Moreover, the

SC8 and SC8 signals from the binary counter 31 of Figure 1 are applied to the AND gates of the sand logic circuits 185 which correspond to the AND gates 175 and 176 of the logic circuit A of the oil coding circuit 170.

The next pattern generator to be discussed will produce the coding pattern seen in Figure 15D. This Figure 15D pattern comprises alternate light and dark stripes which run

transversely of the record medium. This Figure 15D pattern designates "movable oil". To produce this pattern is the function of the "movable oil coding circuit" 190 of Figure 14. The coding circuit 190 alternately passes and inhibits the pulses generated by the trace length one-shot 177 of the oil coding circuit 170 during alternate two foot sections on the recording medium 36.

To accomplish this, the output pulses from the trace length one-shot 177 of circuit 170 are applied to an AND gate 191 within the movable oil coding circuit 190. The start

and stop signals from the area coding card reader 47 enable the AND gate 191 when the conditional coding format is satisfied. To provide the alternate recording and inhibiting of the pulses generated by the trace length one-shot 177 during successive two foot sections, the two foot sweep signal from the depth interval detector 63 and the sweep control signal from sweep circuit 24 of Figure 1 are combined in an AND gate 192 and the trailing edge of the resulting output pulses from AND gate 192 trigger a toggle flip-flop 193 whose normal output enables the AND gate 191. By this arrangement, the flip-flop 193 will enable the AND gate 191 once every other two foot section to produce the pattern indicated in Figure 15D.

The start and stop signals are combined in an AND gate 194 whose output signal is the area coding blanking signal which is applied to the combining and logic circuits 42 to blank out the writing of scale and depth lines when the movable oil coding pattern is being recorded.

The next pattern generator to be described produces the area coding pattern shown in Figure 15E. It can be seen that this area coding pattern is similar to the one shown in Figure 15D except that the dotting pattern produced for the dark sections is more widely dispersed, thus giving a lighter or greyish appearance to the dark sections thereof. This pattern of Figure 15E designates "movable gas" and is generated by the "movable gas coding circuit" 196 in Figure 14.

The movable gas coding circuit 196 includes a toggle flip-flop 193A which is toggled by the output pulses from the AND gate 192. An AND gate 191A is responsive to the start

and stop signals selected by the area coding card reader for the movable gas coding circuit 196 and the normal output of the flip-flop 193A for passing the trace length pulses produced by logic circuit A of the gas coding

circuit 182. These passed or gated $\overline{SR}/8$ pulses constitute the area coding writing signal from the movable gas coding circuit 196. An AND gate 194A responds to the start and

stop signals selected by the card reader for the movable gas circuit 196 to generate the area coding blanking signal for coding circuit 196.

The difference between the movable gas coding circuit 196 and the movable oil coding circuit 190 is that in the former, the AND gate 191A is responsive to the pulses generated by the trace length one-shot (corresponding to one-shot 117 of coding circuit 170) within logic circuit A of the gas coding circuit 182 while the latter uses the trace length pulses from one-shot 177. Thus, the oil pattern of Figure 15A will make up the dark areas of the movable oil pattern of Figure 15D while the gas pattern of Figure 15B will make up the dark areas of the Figure 15E movable gas pattern. Since the oil dotting pattern of Figure 15A is denser and thus darker in appearance than that for the gas coding pattern of Figure 15B, the dark sections of Figure 15E will appear lighter than those of Figure 15D.

The next pattern generator to be described produces the coding pattern shown in Figure 15F. This coding pattern comprises the absence of all marks in the area for which coding is desired and represents porosity. To produce this pattern is the function of the porosity coding circuit 198 of Figure 14. The porosity coding circuit 198 through an

AND gate 199 merely responds to the stop and start signals selected by the area coding card reader 47 for the porosity coding circuit to prevent the writing of all data between the start and stop logs. The output signal from AND gate 199 constitutes the area coding blanking signal for the coding circuit 198.

The next pattern generator to be described produces the coding pattern of Figure 15G, which is the coding pattern for "water". This coding pattern comprises a light area between the start and stop logs, broken only by the presence of scale lines. To provide this coding pattern, a "water coding circuit" 200 of Figure 14 includes an AND gate 201 which

is responsive to the start and stop signals from the card reader 47 for this circuit for generating the area coding blanking signal which inhibits the writing of data in the area bounded by the start and stop logs. Then, to produce the scale lines, the scale line signal from the OR gate 41 of scale line circuit 37 of Figure 1 is applied to an AND gate 202

which is also responsive to the start and stop signals for producing the area coding writing signal for the water coding circuit. Thus, the AND gate 202 reinserts the scale line signals which have been inhibited by the action of the AND gate 201.

The next pattern generator to be described

produces the coding pattern of Figure 15H which is the pattern for a type of shale which, for present purposes, is designated shale No. 1. As seen in Figure 15H, this coding pattern is defined by vertically spaced apart dashed lines wherein the dashes are staggered from one depth level (transverse or vertical lines on the record medium) to the next and is generated by the shale No. 1 coding circuit 205 of Figure 14.

Within the coding circuit 205, a flip-flop 206 is set by the SR/16 pulses and reset by

the SR pulses. The rising edge of the normal output of flip-flop 206 toggles a toggle flip-flop 207 whose normal and complementary outputs enable a pair of AND gates 208 and 209 respectively to pass the sweep counter

31 square wave signals SC16 and SC16 respectively. The outputs of both AND gates 208 and 209 energize a trace length one-shot 210 which generates a pulse whose duration is selected to produce a trace length corresponding to those shown in Figure 15H. The output pulses from the trace length one-shot

210, along with the start and stop signals selected by the area coding card reader 47 for this coding circuit are combined in an AND gate 211. The resulting output signal from AND gate 211 constitutes the area coding writing signal for the shale No. 1 coding circuit 205. An AND gate 212 is

responsive to the start and stop signals selected for this coding circuit for producing the area coding blanking signals.

It can be seen that the flip-flop 206 will be set once every sixteen sweeps to thereby cause the energization of the trace length one-shot 210 once per 16 sweeps. The vertical or transverse distance between the initiation of each trace written on the recording medium

is set by the SC16 and SC16 counter signals. By way of comparison, this distance for the shale No. 1 pattern is eight times greater than that for the oil pattern of Figure 15A

since the counter signals SC2 and SC2 are used by the oil coding circuit 170. It can be seen that every other time the flip-flop 206 is in its normal state, one or the other of the AND gates 208 and 209 will be enabled to

pass the SC16 and SC16 signals respectively thus causing the traces to be staggered on the recording medium 36.

The next pattern generator to be described will produce the coding pattern shown in Figure 15I which corresponds to a second type of shale, designated "shale No. 2". As seen in Figure 15I, this coding pattern is

similar to the coding pattern of Figure 15H except that the vertically directed dashes are longer and further spaced apart. This coding pattern is generated by the shale No. 2 coding circuit 215 of Figure 14. To produce this pattern, the coding circuit 215 uses the normal output of the flip-flop 207 of the coding circuit 205 to enable a pair of AND gates 216 and 217 which are also responsive to the

sweep counter signals SC32 and SC32 respectively. The output pulses from AND gates 216 and 217 energize a trace length one-shot 218. An AND gate 211 passes these trace length pulses as the area coding writing signal for coding circuit 215 when the start

and stop signals selected for this circuit 215 are both at the "one" level. As before, an

AND gate 221 responds to the start and stop signals selected for circuit 215 to produce the area coding blanking signal for this circuit.

Since the normal output of the flip-flop 207 will be one-half the frequency of the flip-flop 206 output signal, the sweeps for which traces are recorded will be twice as far apart as for the shale No. 1 coding pattern. Like-

wise, since the SC32 and SC32 counter signals

are used instead of SC16 and SC16, the trace length one-shot 218 of the shale No. 2 coding circuit 215 is energized one-half as often as for the shale No. 1 coding circuit 205. The trace length one-shot 218 has a timing circuit set to produce pulses having a pulse with greater than that for the trace length one-shot 210 of coding circuit 205 to produce longer length dashes on the record medium 36. To provide for staggering the dashes on alternate writing sweeps, the AND gates 216 and 217 are alternately enabled by the flip-flop 219 to pass the counter

signals SC32 and SC32 on alternate writing sweeps.

The next pattern generator to be described will produce the coding pattern of Figure 15J which designates limestone. This coding pattern is made up of a plurality of spaced vertical lines having interconnecting horizontal lines between each pair of vertical lines, which horizontal lines are vertically staggered from one pair of vertical lines to the next. The circuit for generating this pattern is the limestone coding circuit 225 of Figure 14.

To produce the spaced apart vertical lines, and AND gate 226 is responsive to the coincidence of the two foot sweep signal and sweep control signal from the AND gate 192

and the start and stop signals selected by the area coding card reader 47 for this coding circuit 225 to produce a vertical (transverse

to the record medium) line once every two feet. To produce the staggered horizontal lines, the rising edges of the two foot sweep control signal from AND gate 192 toggles a divide by two flip-flop 227 whose normal and complementary outputs enable a pair of AND gates 228 and 229 respectively. When enabled, the AND gates 228 and 229 pass the sweep

counter signals SC32 and SC32 to energize a trace length one-shot 230. The time period of the pulses generated by the one-shot 230 are small so as to produce dots on the recording medium. The output pulses from the trace length one-shot 230 are then combined in an

AND gate 227 with the start and stop signals selected for this coding circuit so as to produce writing signals which will produce the staggered horizontal line shown in Figure 15J.

The output signals from AND gates 226 and 227 are then combined to produce the area coding writing signal for the limestone coding circuit 225 to produce the pattern of Figure 15J. As before, the area coding blanking signal is produced by combining the start

and stop signals in an AND gate 228.

Summarizing the operation of this limestone coding circuit 225, the AND gate 226 operates to produce the vertical lines shown in Figure 15J. (In actuality, the area coding blanking signal produced by the AND gate 228 inhibits the writing of depth line between the start and stop logs and the AND gate 226 merely reinserts the two foot depth lines in this area.) To produce the horizontal lines,

the edge of one of the SC32 and SC32 square wave counter signals periodically energizes the trace length one shot 230 to produce dots on the recording medium at the same vertical position during each sweep. Thus, during a succession of sweeps, a horizontal line will be produced. Then, when the next two foot depth line is reinserted by the AND gate 226 in the area normally set aside for area coding, the two foot sweep control signal from AND gate 192 which causes the depth line to be reinserted also toggles the divide by two flip-flop 227 to reverse the enable-disable configuration AND gates 228 and 229 and thus

of SC32 and SC32. By so doing, the staggering of the horizontal lines between vertical line pairs is produced.

The next pattern generator to be described produces the area coding pattern of Figure 15K, which represents dolomite. As seen in Figure 15K, this pattern is very similar to the limestone coding pattern of Figure 15J except that the horizontal lines for limestone are slanted for dolomite. To produce this coding

pattern is the function of the dolomite coding circuit 235 of Figure 14.

The reinsertion of the two foot depth line is produced in this circuit 235 by an AND gate 236 which is responsive to the coincidence of the two foot sweep signal and the sweep control signal, and the

start and stop signals selected by the area coding card reader 47 for this coding circuit.

This is essentially the same function as was performed by AND gate 226 of the limestone coding circuit 225. To produce the slanted lines between the two foot vertical lines, the rising edges of the square wave output signals produced by either of the AND gates 228 or 229 of the limestone coding circuit 225 set a flip-flop 237. When the flip-flop 237 is set, an AND gate 238 is enabled to pass the clock pulses designated CL from the sweep circuit 24 of Figure 1 to the count input of a down counter 239 ("down counter" signifies that this counter 239 subtracts a count for each pulse supplied thereto). When the contents of the down counter 239 have been completely subtracted away, the leading edge of the resulting borrow pulse resets the flip-flop 237. When the flip-flop 237 is reset, a trace length one-shot 240 generates a short time duration pulse which, during the coincidence

of the start and stop signals selected by the area coding card reader 47 for this coding circuit, is passed by an AND gate 241 as part of the area coding writing signal for this coding circuit. The outputs of AND gates 236 and 241 comprise the area coding writing signal for the dolomite coding circuit.

What has been described thus far in the dolomite coding circuit 235 would produce the limestone pattern of Figure 15G given by the limestone coding circuit 225, i.e., the lines between the vertically extending two foot depth line would be horizontal. To provide for slanting lines, a binary counter 242 is advanced one count for each sweep reset signal applied to its count input, i.e., it is advanced one count per sweep. The leading edge of the sweep reset pulses causes the counter 242 to advance. The contents of the binary counter 242 are transferred to the down counter 239 in response to the trailing edges of the pulse from the one-shot 240. Thus, for each sweep of the CRT beam, the number placed in the down counter 239 increases by one count thus causing the down counter 239 to receive one more CL pulse per sweep for the contents thereof to be emptied. Consequently, it takes a slightly greater time for each additional sweep for the trace length one shot 240 to be energized thus producing a slanted line.

At every two foot depth interval, the binary counter 242 is reset by the two foot sweep control signal from AND gate 192 to initiate

the production of the slanted line between the next pair of two foot depth lines. Since the two foot sweep control signal toggles the flip-flop 227 for alternately enabling AND gate 228 and AND gate 229, the slanted lines will be staggered because of the alternate

selection of the SC32 and SC32 counter signals by the AND gates 228 and 229.

The area coding blanking signal is produced by an AND gate 243 in response to the

start and stop signals in the usual manner.

The last pattern generator to be described produces the coding pattern of Figure 15L which identifies anhydrite and is produced by the anhydrite coding circuit 245. This coding pattern is a slanted line pattern within the area bounded by the start and stop logs selected by the card reader 47. To produce this pattern, a divide by 40 counter 247 counts both the clock pulses CL from the high frequency clock 29 of Figure 1 and the sweep reset pulses from the sweep circuit 24 of Figure 1, which are combined in an OR gate 246. An edge of the square wave output signal from the counter 247 energizes a trace length one-shot 248 which generates pulses having a short time duration so as to produce dots on a recording medium. These pulses generated by the one-shot 248 are combined in an AND gate 249 with the

start and stop signals so that the coding pattern will be produced only between the selected start and stop logs. The start and

stop signals are also combined in an AND gate 250 to produce the area coding blanking signal in the same manner as discussed previously.

Neglecting for the moment the effect of the sweep reset pulses, the clock pulses would, after division by the divide by forty counter 247, cause a dot to be placed on the recording medium at the same vertical (or transverse) position for each sweep, thus producing a plurality of horizontal lines spaced apart a distance corresponding to $CL/40$. However, since the sweep reset pulses are also counted by the counter 247, the net effect is to move the vertical point at which the dot is recorded for each sweep a given vertical increment. Thus, since the recorded dot is moved a given vertical increment for each sweep, the net result is to produce slanted lines within the area defined by the start and stop logs.

Various features of the methods and means for generating the various coding patterns hereinbefore described form the subject of our copending U.K. Patent Application No. 59270/73 (Serial No. 1,357,152) divided herefrom.

Now, referring to Figure 17, there is

5 shown the combining and logic circuit 42 and the CRT brightness control circuits 50 of Figure 1 in greater detail. First, concerning the combining and logic circuit 42, it is the function of this circuit to combine the writing signals from the parallel line coding circuits 45, the area coding circuit 48, as well as the trace intensified writing signals from card reader 49, and the scale and depth line signals from the scale line circuit 37 and depth line generator 64 for application to the CRT 25. In addition to these combining operations, circuit 42 also performs certain logic operations to give a desired recording format.

10 The line coded writing signals from the line coding circuits 45 of Figure 1 are combined in an OR gate 260 and the area coding writing signals from the area coding circuits 48 are combined in an OR gate 261. The outputs of OR gates 260 and 261 are combined in OR gate 262 for application to one input of an AND gate 263.

15 As discussed earlier, no data is to be written on the recording medium while the initial scale line is being printed and during the fly-back of the cathode ray tube beam, i.e., during sweep reset. Therefore, the initial scale line and sweep reset pulses, after inversion by a pair of invokers each constituted by a respective, suitably connected NAND gate, 264 and 265 respectively, are applied to individual inputs of the AND gate 263 so as to inhibit any writing signals from OR gate 262 during printing of the initial scale line and fly-back of the cathode ray tube beam. The output of the AND gate 263 is applied to a limiter circuit 266 which sets the desired voltage level for the output signals from and gate 263 and then applies the signals to the CRT brightness control circuit 50.

20 The scale and depth lines are combined in an OR gate 267 for application to a limiter circuit 268 which performs the same function as limiter circuit 266 and then applies the scale and depth line signals to the CRT brightness control circuit 50. To insure that a depth line signal is generated only during the time the beam is being swept across the usable portion of the recording medium, the depth line signal and sweep control signal are combined in an AND gate 269 before being applied to the OR gate 267. Moreover, since as discussed earlier scale and depth lines are not to be written

25 in the depth track, the depth track inhibit signal from the scale grid card reader 38 (see Figure 1) is used to disable the AND gate 269 and an AND gate 270 to which the scale line signals are applied whenever the CRT beam is being swept through the depth track. Also depth and scale lines are not to be recorded whenever one of the area

coding pattern generators is operating to produce a pattern (except where the pattern generator itself reinserts the depth or scale line) or when a channel signal is being recorded. To accomplish this function, the area coding blanking signals from the area coding circuits 48 are combined in an OR gate 271 and the output of this OR gate is combined with the output of AND gate 263 in an OR gate 272. The output signal from the OR gate 272 thus represents the combination of the area coding blanking signal and the line and area coding writing signals. Since scale and depth lines are not to be recorded when any of these other signals are processed for recording, the output control signal from OR gate 272 is inverted by an inverter constituted by a suitably connected NAND gate 273 and applied to the input of an AND gate 274, to which also is supplied the output from OR gate 267. Thus, the AND gate 274 will be disabled whenever the channel signals are being recorded and during area coding.

30 In addition to the above, the combining and logic circuit 42 also combines the trace intensifier signals from the trace intensifier card reader 49 of Figure 1 in an OR gate 275, and the amplitudes of the signals from OR gate 275 are limited by a limiter circuit 276 before application to the CRT brightness control circuit 50. The amplitude level of the limiter circuit 276 is set high enough to enable a higher amplitude level for these trace intensified output signals from OR gate 275 than the scale and line signals from gates 267 and 274 and the line and area coded writing signals from AND gate 263.

35 Now, concerning the CRT brightness control circuit portion of Figure 17, the line and area coded writing signals, scale and depth line signals, and trace intensifier signals from the limiter circuits 266, 268, and 276 respectively of the combining and logic circuit 42 are fed to the negative or inverting input of an operational amplifier 280 via summing and weighting resistors 281, 282 and 283 respectively. The values of these resistors 281, 282 and 283 are set in conjunction with the limiting values of the limiter circuits 266, 268 and 276 to bring about the proper relationship of trace intensities for the coded writing signals, scale and depth line signals, and trace intensifier signals. These combined signals are then further processed by the CRT brightness control circuits 50 for use in unblanking the CRT beam.

40 With a CRT having a fiber optic faceplate, the anode must be operated at ground potential, thus necessitating that the grid and cathode be at a high negative potential, e.g., approximately -10,000 volts. Since the signals of the operational amplifier 280 are within a few volts of ground potential, these signals must be translated through a level of

thousands of volts. To alleviate this problem, a transformer 284 isolates the two circuits and the amplitude of a high frequency signal produced by an oscillator 282 is controlled by the output signals from amplifier 280. To this end, the amplifier 280 signals control the gain of a variable gain amplifier 281 to which the high frequency signal from oscillator 282 is applied. The output signal from amplifier 281 feeds the primary winding 283 of a transformer 284 with one side of the primary winding 283 being connected to the same circuit ground as the amplifier 283. On the secondary side of the transformer 284, the signals are detected by the detector 285, i.e., converted to signals which resemble the signals produced by the amplifier 280, and applied to an amplifier and pulse shaper 286. This circuit 286 operates to produce the final amplification to obtain the voltage level necessary for the cathode ray tube 25 and shape the pulses in a manner to compensate for the non-linear effects of the cathode ray tube 25.

As discussed earlier, the beam intensity of a cathode ray tube can vary during the operation of the tube. Of course, such a variation in beam intensity would be undesirable for present purposes because it would tend to vary the quality of the recording. To alleviate this problem, a current to voltage converter 287 monitors the beam current at the anode of the cathode ray tube 25 and supplies a voltage proportional thereto to the summing input of the amplifier 280 to thereby maintain this beam current constant. However, since the beam current is being modulated in accordance with the information to be recorded, the beam current cannot be monitored indiscriminately because of the wide fluctuation or variation in this modulation during any given sweep.

To provide a valid measure of beam current, a sample and hold circuit 288 is responsive to the initial scale line signal from the scale line circuit 37 of Figure 1 for instructing the sample and hold circuit 288 to sample the voltage output of the converter 287 only when the initial scale line is being recorded. It will be recalled from the discussion of Figure 1 that the initial scale line pulse was combined with the other scale line pulses in the OR gate 41 for application to the combining and logic circuit 42 as the "scale line signals". It will also be recalled from the discussion of the combining and logic circuit 42 of Figure 17 that the initial scale line pulse caused all other writing signals to be inhibited. Thus, it can safely be assumed that the output signal from the amplifier 280 will always be of constant amplitude while the initial scale is being recorded.

Since the sample and hold circuit 288 operates to sample this beam current only

when the initial scale line is being recorded, the beam current can be measured once per sweep and adjusted in response to this measurement to provide the desired beam intensity throughout the remainder of the sweep. To this end, the output signal from the sample and hold circuit 288 is applied to a low pass filter 287 which filters out transients occurring during this sampling process and applies the measured beam current indication signal to a suitable meter 290 and to the summing input of the amplifier 280 via a summing resistor 291. The time constant of the low pass filter 289 can be selected high enough to prevent one or two erroneous measurements from completely upsetting the appearance of the recording, i.e., the feedback system will only respond to relatively slow changes in beam current intensity.

A "brightness adjust potentiometer" 292 also provides current to the summing input of the amplifier 280 via a summing resistor 293. The position of the potentiometer 292 can be preset to give the desired brightness level.

The recording system described up to this point derives data from telemetry equipment for recording. It would also be possible to record data while the exploring device which makes the measurements is moved through the borehole. This could be accomplished by recording the measurements derived directly from the downhole exploring device or recording this data after it has been digitized by a digital tape recorder.

First concerning the recording of data from a digital tape recorder simultaneously with writing the well logging measurements on magnetic tape, refer to Figure 18. In Figure 18, a well tool 300 is suspended in a borehole 301 by a multi-conductor cable 302 for investigating the surrounding earth formations 303. The measurement signals produced by the well tool 300 are transmitted to suitable signal processing circuits 304 over the conductors of the cable 302. The signal processing circuits operate to, for example, reference the signals to a common reference potential and depth. The processed signals are then applied to a digital tape recorder 305 which digitizes the measurements and writes them on magnetic tape. The tape recorder 305 could comprise any digital tape recorder. One example of a suitable tape recorder is disclosed in U.S. Patent No. 3,457,544 granted to G. K. Miller et al on July 22, 1969.

This Miller et al tape recorder produces a plurality of signals which are used by the recording equipment of the present invention. It produces a plurality of channel selection signals 306 which designates the channel for which PCM data on a conductor 307 corresponds to. It also generates shift pulses for use by exterior equipment in shifting the

PCM data into a suitable entry register and a "shift pulse window" for use in properly gating the shift pulses to insure that the proper number of shift pulses are used. Finally, it generates a "depth word" signal whenever a depth word is on the PCM data line 307. To produce the digital data words as a function of borehole depth, a shaft 313 which is rotatably connected to a wheel 314 in rotatable engagement with the cable 302 is connected to the input of the tape recorder 305. This shaft causes a circuit within the tape recorder 305 to generate incremental depth pulses at given depth increments which are used to initiate the digitizing operation. For more information on this tape recorder and how it produces these signals, refer to the Miller et al Patent No. 3,457,544.

Now concerning how the digital data from the tape recorder 305 is processed for application to the recording equipment of Figure 1, the PCM data line 307 from the tape recorder 305 is connected to the inputs of a plurality of individual storage resistors 308. The particular register which the PCM data is entered into is selected by the channel designation signals on conductors 306, i.e., one channel designation conductor at a time will be active to thereby activate one storage register at a time to enter the PCM data. The shift pulses and shift pulse window signal from the tape recorder 305 are combined in an AND gate 309 for application to each of the individual storage registers 308. Thus, a particular storage register will be selected by one of the channel designation signals and the PCM data will be entered into this selected register under control of the gated shift pulses.

The output stages of the storage registers 308 are connected to digital to analog converters 309, the output stages of each storage register 308 being connected to an individual digital to analog converter. Thus, each converter 309 will produce an analog output signal whose amplitude is proportional to the digital number contained in each storage register 308, i.e., one analog signal per channel.

As set forth in the Miller et al tape recorder patent, word 1 of each frame is reserved for the depth word. Since there is no need to convert depth words into analog quantities, the analog signals from converters 309 are sampled during the time period when the depth word is being processed by the tape recorder 305. To this end, the leading edge of the depth word control signal from tape recorder 305 energizes a "strobe one-shot" 310 which applies a strobe pulse to suitable sample and hold circuits 311. When strobed, the sample and hold circuits 311 sample the analog voltages from the digital to analog converters 309. The stored analog signals in sample and hold circuits 311 are then applied

to the filters 22 of Figure 1 in place of the signals from the telemetry unit 20.

A plurality of bias circuits 312 operate to selectively bias the analog well logging signals to place them in selected tracks on the recording medium. In the Figure 1 system, it was assumed that this bias operation was taken care of prior to processing of the data by the Figure 1 circuits, i.e., the data outputted from the input equipment 20 already include the proper bias. Of course, if desired, bias circuits could be included in the Figure 1 apparatus (just after the low pass filters 22) to perform this operation.

To supply the depth data to the Figure 1 recorder circuits, the shift window, depth word designation signal and shift pulses are all applied to the AND gate 91 of Figure 4 so as to enable the PCM depth word to be entered into the entry register 90. The depth word is then processed in the manner discussed earlier to provide depth indications on the recording medium.

In this case where the well logging measurements are recorded while they are being made by the well tool 300, the recording medium is driven by the shaft 313. In this case, also for optimum result, the CRT beam sweep repetition rate should not be at a constant frequency. Of course, for good recording resolution, there should be a plurality of sweeps between sampling and digitizing of the well logging measurements. In the Miller et al tape recording system, the depth word designation signal is generated every time the well logging measurements are sampled, for most applications. Thus, the strobe pulse from the one-shot 310, which was energized by the depth word designation signal, is applied to a sweep pulse generator 315. The generator 315 generates a plurality of pulses per strobe pulse which are applied to the set input of the sweep control flip-flop 27. In this embodiment, the 120 Hertz pulse generator 26 would be disconnected.

The sweep pulse generator 315 could take the form of a pulse generator which generates a fixed number of pulses when energized. Each generated pulse would energize a recorder drive stepping motor 316 which when energized, would cause the recording medium to step a predetermined incremental distance. This stepping of the recording medium is synchronized with the sweep of the beam across the face of the cathode ray tube.

It is not necessary to use a digital tape recorder to supply "real time" data to the recorder of the present invention. Instead, the well logging measurements could be applied directly to the present recorder. Turning to Figure 19, there is shown such an arrangement. The well logging measurements from signal processing circuits 304 are

applied directly to parallel sample and hold circuits 320. To strobe the circuits 320, a depth pulse generator 321 generates a pulse each given incremental movement of the shaft 313. These depth pulses also energize the sweep pulse generator 322 which performs the same function as the generator 315 of Figure 18.

To provide the depth information to the recording equipment of the present invention, the shaft 313 is connected to a depth encoder 343 which can, if desired, take the form of the depth encoder illustrated in the Miller et al tape recorder patent. The digitized depth data is then transferred to the depth determination circuits 60 of Figure 1. In this Figure 19 case, the data could be transferred in parallel to the circuits 60 thus eliminating the necessity of shift pulses and the shift pulse window.

It can thus be seen from the foregoing that new and improved methods and apparatus have been provided for recording well logging data. This has been accomplished by utilizing a cathode ray tube for recording such signals. A recording system has been shown and described which not only can record data as it is being derived from a well logging tool in a borehole, but can also record data being transmitted or received over a telemetry link as well as data which has been previously recorded on magnetic tape and then played back to the recorder. The recorder of the present invention can provide any desired pattern of scale and depth lines. Moreover, this recorder is able to produce any number of line and area coding patterns as desired to thereby enable easy identification of not only individual logs recorded on the recording medium, but also parameters represented by the areas between certain selected logs. This coding can be conditional by allowing area coding only when these logs maintain certain selected relationships to one another. Moreover, good quality recordings can be obtained regardless of the rate of change of the signals to be recorded.

It should be pointed out here that the techniques of the present inventions could be used with other types of recording devices than the fiberoptic CRT shown here. For example, an electrostatic recorder could be used just as well. Such an electrostatic recorder would have a plurality of wire ends positioned transversely across a record medium. The proper wire end would be energized to produce a mark at the proper position.

While there has been described what is at present considered to be preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made in the instrument without departing from the invention, and it is, therefore, intended to

cover all such changes and modifications as fall within the scope of the appended claims.

WHAT WE CLAIM IS:—

1. Apparatus for recording or displaying signals of the type representing well logging data as a function of depth, comprising means for directing energy toward a medium, sweep means adapted for sweeping the energy along a line transverse to the medium during successive sweep intervals to place images in the form of dots or linear marks on the medium, timing means for controlling placement of the images in the direction of such line with reference to an initial position, means for producing relative movement between the medium and the line swept by the energy in a direction substantially perpendicular to the line swept by the energy, and means for controlling the level of the energy to regulate the intensity, wherein said timing means provides clock pulses for digitally generating a sweep signal to control the sweep means and a reset signal to determine the sweep duration, and said level control means is responsive to at least the or each data signal and said sweep signal to determine the placement and linear extent of the images and thereby the apparent intensity of lines, traces or patterns to be formed by such images, whereby said lines, traces or patterns are representative of at least the variation of the or each data signal as a function of depth.

2. Apparatus according to claim 1 further characterized in that said timing means includes a counter and provides said reset signal after a predetermined count to make uniform the length of each sweep signal.

3. Apparatus according to any of the preceding claims characterized in that a scale line generator is coupled to said timing means and to said level control means to provide scale line images at fixed displacements from the initial position during successive sweep intervals.

4. Apparatus according to claim 3 characterized in that said scale line generator includes means coupled to said level control means to increase the linear extent of selected ones of said scale line images to differentiate their apparent intensity.

5. Apparatus according to any of the preceding claims further characterized by a depth line signal generator, said level control means being responsive to the depth line signal and the reset signal to provide depth line images transverse to the medium.

6. Apparatus according to claim 5, characterized in that said depth line signal generator is responsive to signals representing selected depth values to provide one of plural successive depth line images to differentiate by their apparent intensity depth lines marking said selected depth values.

applied directly to parallel sample and hold circuits 320. To strobe the circuits 320, a depth pulse generator 321 generates a pulse each given incremental movement of the shaft 313. These depth pulses also energize the sweep pulse generator 322 which performs the same function as the generator 315 of Figure 18.

To provide the depth information to the recording equipment of the present invention, the shaft 313 is connected to a depth encoder 343 which can, if desired, take the form of the depth encoder illustrated in the Miller et al tape recorder patent. The digitized depth data is then transferred to the depth determination circuits 60 of Figure 1. In this Figure 19 case, the data could be transferred in parallel to the circuits 60 thus eliminating the necessity of shift pulses and the shift pulse window.

It can thus be seen from the foregoing that new and improved methods and apparatus have been provided for recording well logging data. This has been accomplished by utilizing a cathode ray tube for recording such signals. A recording system has been shown and described which not only can record data as it is being derived from a well logging tool in a borehole, but can also record data being transmitted or received over a telemetry link as well as data which has been previously recorded on magnetic tape and then played back to the recorder. The recorder of the present invention can provide any desired pattern of scale and depth lines. Moreover, this recorder is able to produce any number of line and area coding patterns as desired to thereby enable easy identification of not only individual logs recorded on the recording medium, but also parameters represented by the areas between certain selected logs. This coding can be conditional by allowing area coding only when these logs maintain certain selected relationships to one another. Moreover, good quality recordings can be obtained regardless of the rate of change of the signals to be recorded.

It should be pointed out here that the techniques of the present inventions could be used with other types of recording devices than the fiberoptic CRT shown here. For example, an electrostatic recorder could be used just as well. Such an electrostatic recorder would have a plurality of wire ends positioned transversely across a record medium. The proper wire end would be energized to produce a mark at the proper position.

While there has been described what is at present considered to be preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made in the instrument without departing from the invention, and it is, therefore, intended to

cover all such changes and modifications as fall within the scope of the appended claims.

WHAT WE CLAIM IS:—

1. Apparatus for recording or displaying signals of the type representing well logging data as a function of depth, comprising means for directing energy toward a medium, sweep means adapted for sweeping the energy along a line transverse to the medium during successive sweep intervals to place images in the form of dots or linear marks on the medium, timing means for controlling placement of the images in the direction of such line with reference to an initial position, means for producing relative movement between the medium and the line swept by the energy in a direction substantially perpendicular to the line swept by the energy, and means for controlling the level of the energy to regulate the intensity, wherein said timing means provides clock pulses for digitally generating a sweep signal to control the sweep means and a reset signal to determine the sweep duration, and said level control means is responsive to at least the or each data signal and said sweep signal to determine the placement and linear extent of the images and thereby the apparent intensity of lines, traces or patterns to be formed by such images, whereby said lines, traces or patterns are representative of at least the variation of the or each data signal as a function of depth.

2. Apparatus according to claim 1 further characterized in that said timing means includes a counter and provides said reset signal after a predetermined count to make uniform the length of each sweep signal.

3. Apparatus according to any of the preceding claims characterized in that a scale line generator is coupled to said timing means and to said level control means to provide scale line images at fixed displacements from the initial position during successive sweep intervals.

4. Apparatus according to claim 3 characterized in that said scale line generator includes means coupled to said level control means to increase the linear extent of selected ones of said scale line images to differentiate their apparent intensity.

5. Apparatus according to any of the preceding claims further characterized by a depth line signal generator, said level control means being responsive to the depth line signal and the reset signal to provide depth line images transverse to the medium.

6. Apparatus according to claim 5, characterized in that said depth line signal generator is responsive to signals representing selected depth values to provide one of plural successive depth line images to differentiate by their apparent intensity depth lines marking said selected depth values.



7. Apparatus according to claim 5 or 6, characterized in that said level control means is responsive to said clock pulses to inhibit depth line images over a selected interval of said medium. 65
8. Apparatus according to any of the preceding claims further characterized by line coding means coupled to said level control means and responsive to data signals and to said sweep signal for line coding a trace representative of respective data signals. 70
9. Apparatus according to claim 8 characterized in that said line coding means is further responsive to said reset signals for coding said trace by producing timed interruptions therein. 75
10. Apparatus according to any of the preceding claims further characterized by signal comparison means responsive to the rate of change of a data signal for controlling the linear extent of images or of interruptions of a trace representative of such data signal. 80
11. Apparatus according to claim 10 characterized in that the linear extent of an image is increased by said comparison means transversely of the medium with increase in said rate of change of a data signal to render more uniform the apparent intensity of the trace representative of said data signal. 85
12. Apparatus according to claim 10 or 11 characterized in that the linear extent of interruptions of a trace is regulated by said comparison means to provide interruptions of substantially uniform length coding the trace for identification with the respective data signal. 90
13. Apparatus according to any of the preceding claims further characterized by pattern generating means responsive to at least one of said data signals for supplying area coding signals to said level control means. 95
14. Apparatus according to claim 13 characterized in that said pattern generating means is further responsive to said sweep signal for supplying area coding signals to said level control means. 100
15. Apparatus according to claims 13 or 14 characterized in that said pattern generating means selectively responds to data signals to provide area coding images between traces representing a selected pair of data signals. 105
16. Apparatus according to any of claims 13 to 15 characterized in that said pattern generating means is responsive to reset signals representing successive sweep intervals correspondingly to provide area coding images having an apparent inclination with respect to the transverse line across said medium. 110
17. Apparatus according to any of the preceding claims further characterized by said level control means being selectively responsive to the level of energy directed toward said medium in fixed relation to said initial position to regulate said energy during the respective sweep interval. 115
18. Apparatus according to claim 17 further characterized by image intensifier means coupled to said level control means for selectively determining the energy level for respective images. 120
19. Apparatus according to any of the preceding claims further characterized by digital logic means for determining the response of said level control means to the respective signals. 125
20. A method of recording or displaying data signals of the type representing well logging data as a function of depth on a recording or displaying medium, comprising the steps of: directing energy towards the medium; generating clock pulses; generating from said clock pulses a sweep signal for periodically sweeping the energy along a line transverse to the medium to place images in the form of dots or linear marks on the medium; timing each sweep of the energy so as to control the placement of the images in the direction of said line with reference to an initial position; generating from said clock pulses a reset signal to determine the duration of each sweep of the energy; producing relative movement between the medium and said line in a direction substantially perpendicular to said line; and varying the level of the energy in dependence on at least the or each data signal and said sweep signal to determine the placement and linear extent of the images and thereby the apparent intensity of lines, traces or patterns to be formed by such images, whereby said lines, traces or patterns are representative of at least the variation of the or each data signal as a function of depth.
21. A method as claimed in claim 20, further comprising the step of forming scale line images by varying the level of the energy to place images at fixed displacements from the initial position during successive sweeps of the energy.
22. A method as claimed in claim 20 or claim 21, further comprising the step of forming depth line images by generating a depth signal, and varying the level of the energy in response to the depth signal and the reset signal to produce said depth line images transverse to the medium.
23. A method as claimed in any of claims 20 to 22, further comprising the steps of producing a respective signal representative of the rate of change of each data signal and varying the level of the energy in response to each rate-of-change signal to control the linear extent of the images or interruptions of trace representative of that data signal.
24. Apparatus for recording or displaying signals of the type representing well logging data as a function of depth, substantially as



hereinbefore described with reference to the accompanying drawings.

25. A method of recording or displaying
signals of the type representing well logging
data as a function of depth, substantially as
5 hereinbefore described with reference to the
accompanying drawings.

K. G. W. SMITH,
Chartered Patent Agent,
Agent for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1974.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.

