Feb. 14, 1967 F. W. ZILL 3,304,538

ACOUSTIC WELL LOGGING DOWNHOLE CONTROL SYSTEM

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Fig. 1

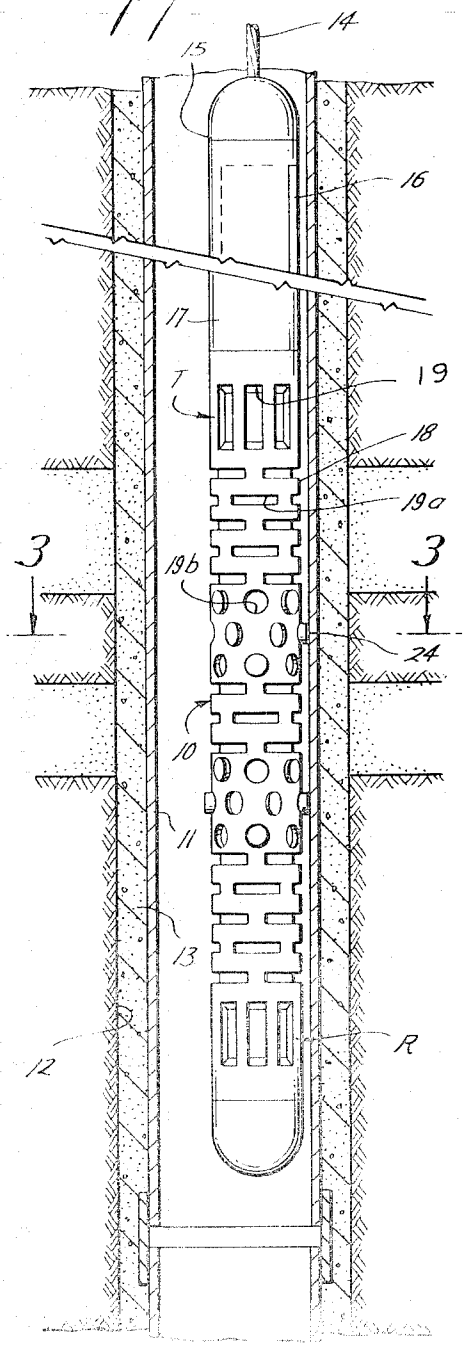
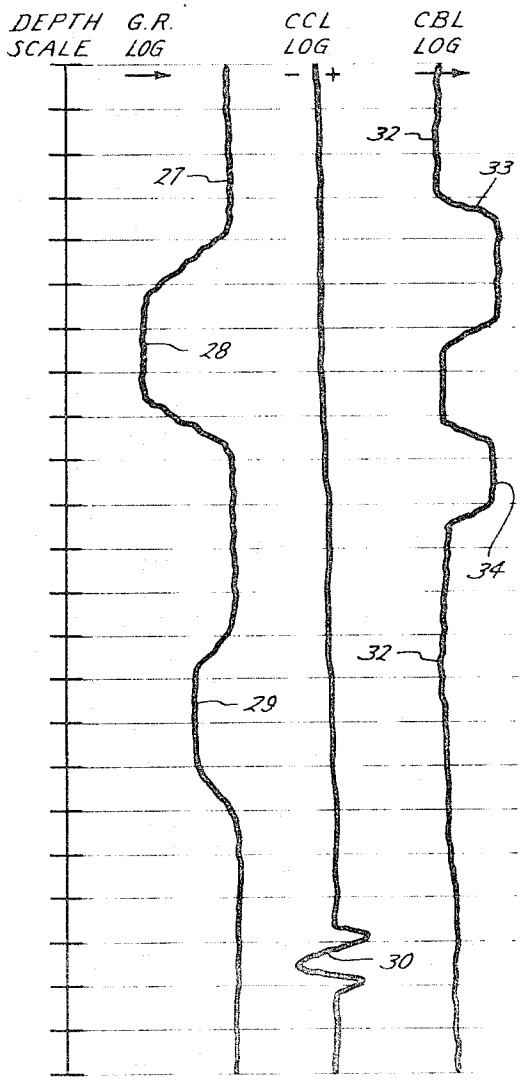


Fig. 2



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ACOUSTIC WELL LOGGING DOWNHOLE CONTROL SYSTEM

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Fig. 3

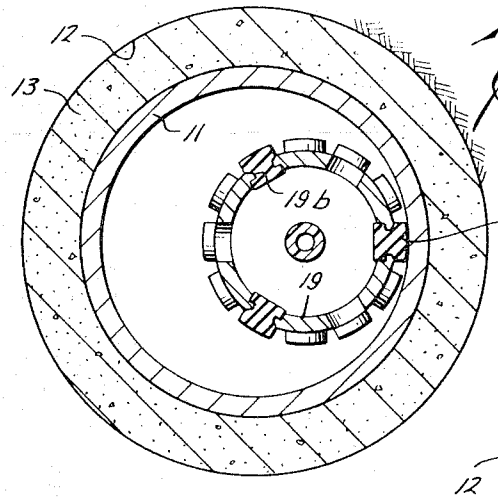


Fig. 4

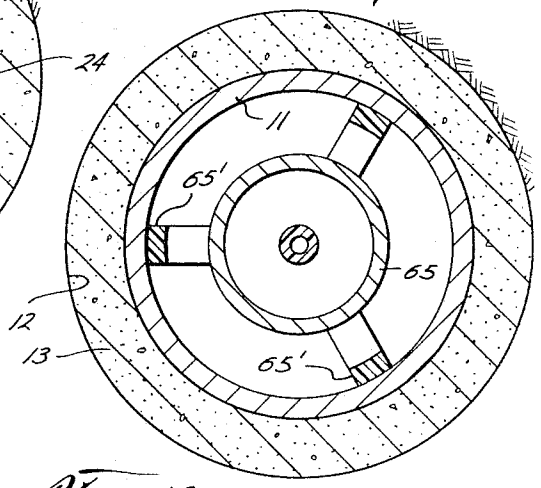


Fig. 9

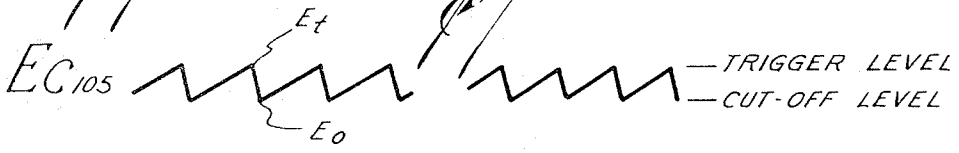
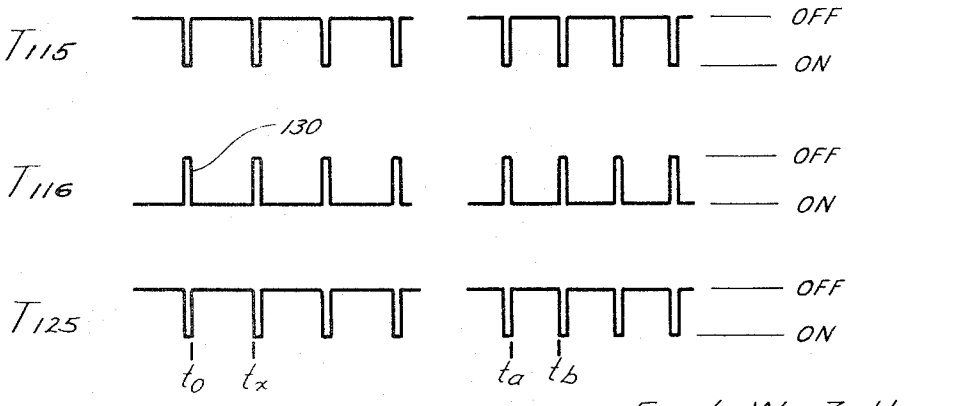


Fig. 10



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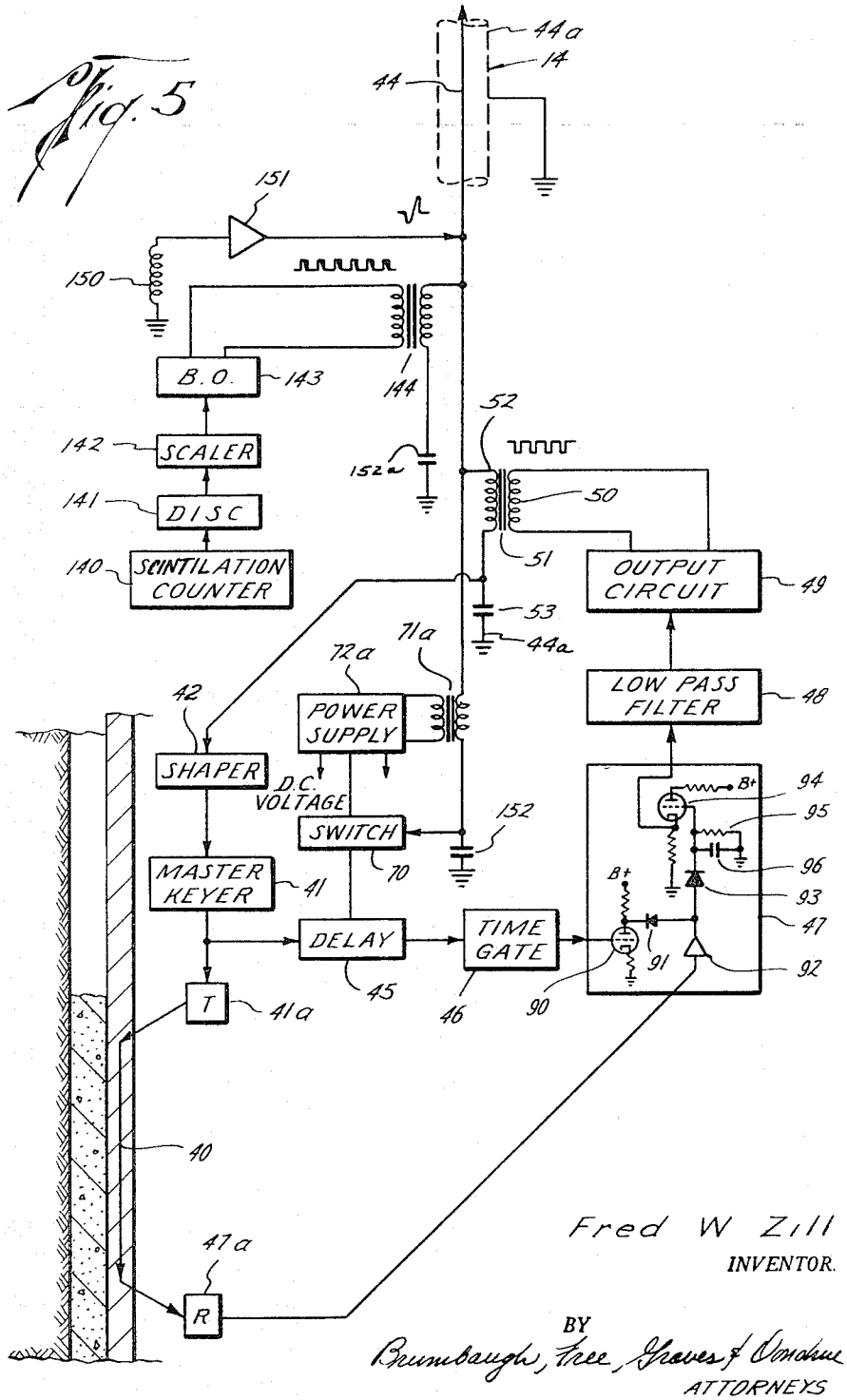
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ACOUSTIC WELL LOGGING DOWNHOLE CONTROL SYSTEM

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Fig. 5



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Fig. 6

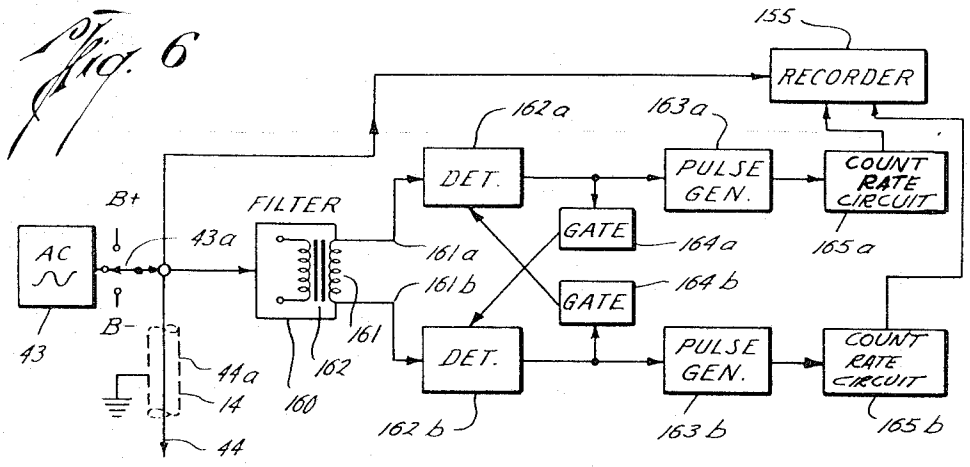
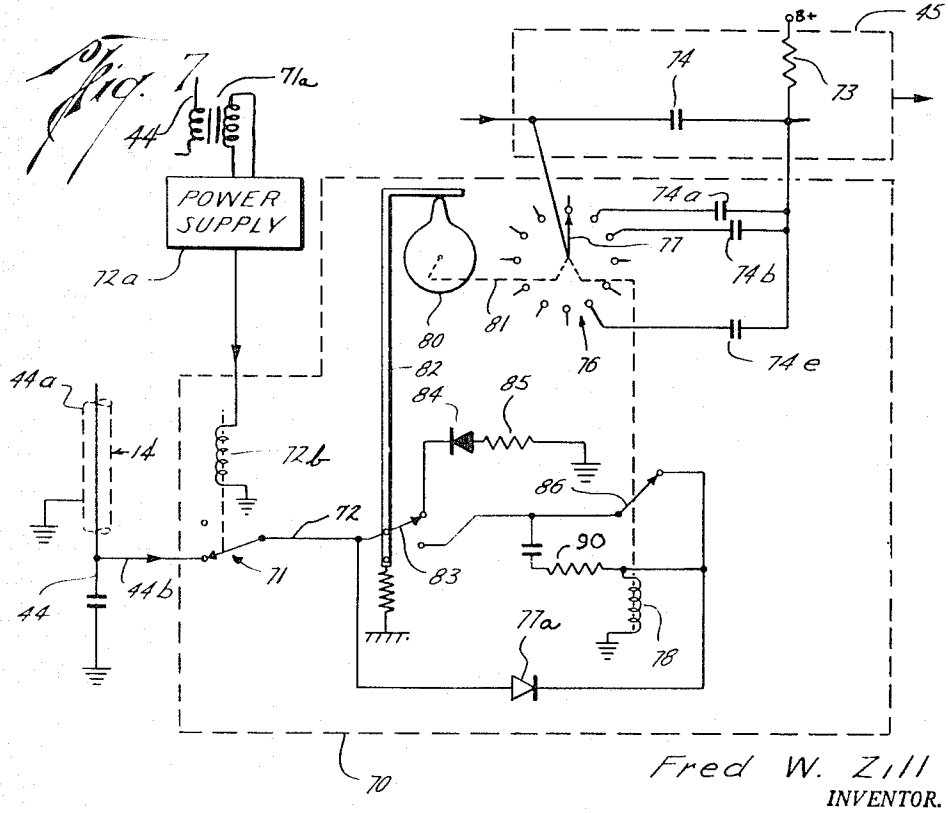


Fig. 7



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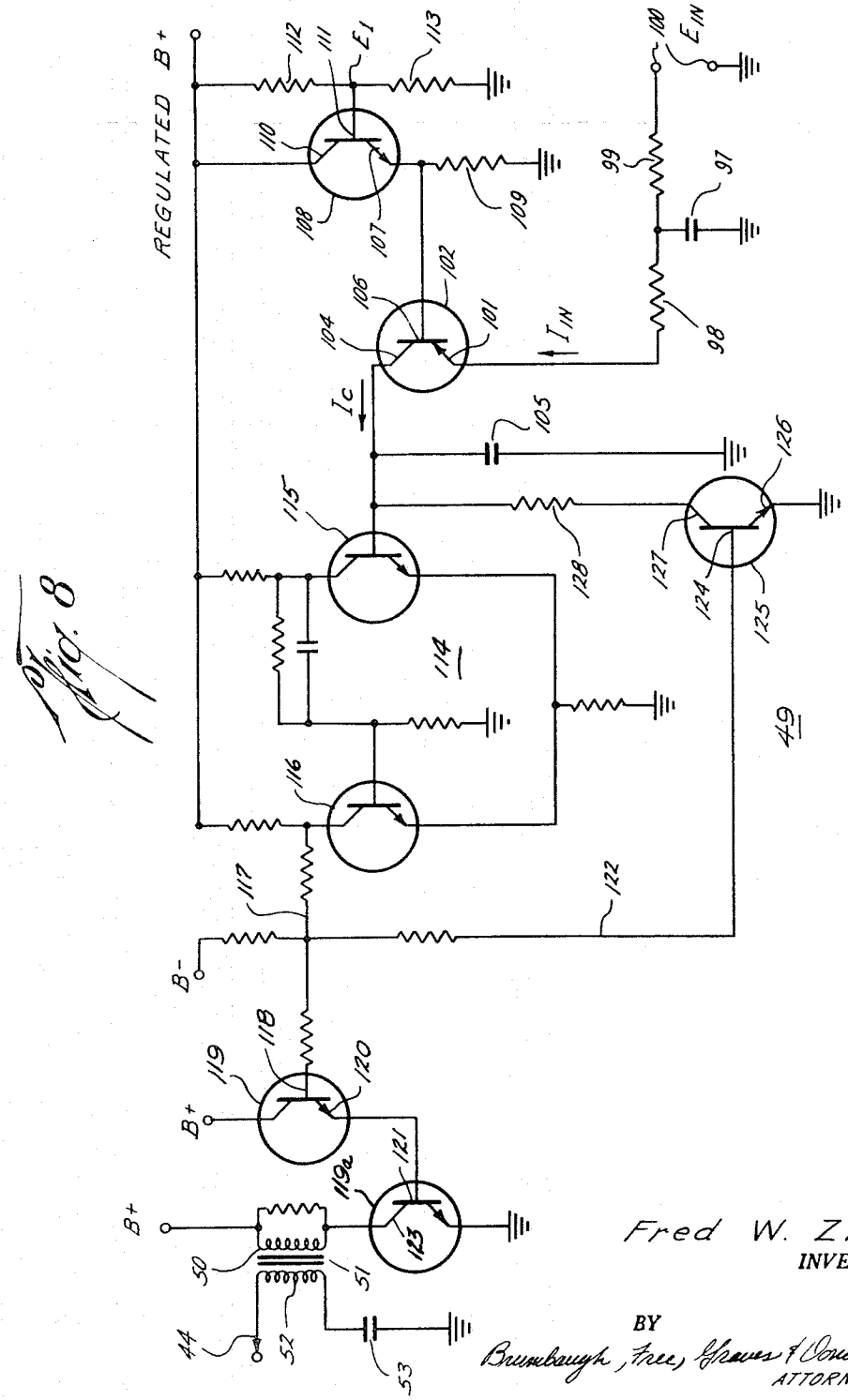


Fig. 8

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United States Patent Office 3,304,538 Patented Feb. 14, 1967

3,304,538

ACOUSTIC WELL LOGGING DOWNHOLE CONTROL SYSTEM

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Original application Aug. 8, 1961, Ser. No. 130,116. Divided and this application Feb. 7, 1966, Ser. No. 525,502

15 Claims. (Cl. 340—18)

This application is a division of my copending application for "Acoustic Logging Tool," Serial No. 130,116, filed August 8, 1961.

This invention relates to exploratory tools for use in well bores and more particularly to tools and systems useful for determining the quality of bonding between a casing and an outer sheath of cement, the location of casing collars, and types of earth formations behind a casing.

In well completion practices, after the selection of a likely production zone, a casing or string of pipe is inserted in the well bore; and cement is pumped into the annulus between the casing and borehole. The cement, upon setting, serves to plug the annular space between the pipe and the borehole to prevent migration of fluids. It is desirable to ascertain after the cementing operation whether the column of cement has adequately plugged the annular space or whether portions of cement failed to completely surround the casing or failed to bond properly to the exterior of the casing. It is also desirable to locate casing collars and the type of formations behind a casing.

In another typical oil field practice, where a recovery operation for a "stuck" drill pipe is contemplated, it is important to know the depth at which the earth formations have seized the pipe. In many instances the packing of the earth formations about the pipe is acoustically analogous to the conditions of a cement bonded pipe in that an acoustic signal is attenuated by the earth formations which are packed about the casing.

Accordingly, it is an object of the present invention to provide new and improved apparatus for logging the quality of cementation in a cased well bore.

It is an object of the present invention to provide new and improved apparatus for ascertaining acoustically the packing of earth formations about a pipe string.

A still further object of the present invention is to provide new and improved apparatus for use in a monocable for logging the quality of cementation in a cased well bore.

A still further object of the present invention is to provide new and improved circuit systems useful in the operation of a well tool suspended in a well bore by means of a monocable.

Another object of the present invention is to provide new and improved circuit systems.

The novel features of the present invention are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments taken in conjunction with the accompanying drawing in which:

FIG. 1 illustrates a section of the earth formations traversed by a cased well bore in which a tool embodying the present invention is disposed.

FIG. 2 illustrates schematicaly a log presentation of typical measurements obtained by use of the apparatus embodying the present invention.

FIG. 3 is a view in cross-section taken along line 3—3 of FIG. 1.

FIG. 4 is a view in cross-section through a section of the earth formations traversed by earth bore and briefly

illustrating in cross-section a modified arrangement for the tool illustrated in FIG. 1.

FIG. 5 is a schematic illustration of the electrical circuitry in the down hole portion of the apparatus of the present invention.

FIG. 6 is a schematic representation of the electrical circuitry at the earth's surface which is coupled to the down hole apparatus for obtaining the log illustrated in FIG. 2.

FIG. 7 is a more detailed circuit illustration of a circuit element schematically illustrated in FIG. 5.

FIG. 8 is a more detailed circuit illustration of a circuit element schematically illustrated in FIG. 5.

FIG. 9 depicts typical electrical wave forms occurring at various points in the circuit illustrated in FIG. 8 for a given input signal.

FIG. 10 depicts typical electrical wave forms occurring at various points in the circuit illustrated in FIG. 8 for another input signal.

Referring now to FIG. 1, an apparatus **10** is shown disposed within a casing **11**, the casing being firmly coupled to the borehole **12** by means of a column of cement **13**. The apparatus **10** is adapted to be suspended in the well bore and passed therethrough by means of a monocable **14** and a conventional winch or pulley (not shown) situated at the surface of the earth. Apparatus **10** is shown positioned to one side of the casing **11** since, in ordinary practice, the casing and/or well bores invariably are inclined relative to a vertical so that the apparatus naturally gravitates to a lowermost side of a well bore.

The apparatus **10** includes an upper housing section **15** containing a magnet **16** which has longitudinally extending north and south poles arranged parallel to one another and suitably spaced from one another to provide magnetic attraction to the upper end of the housing relative to the casing. The magnet **16** thus offsets resultant forces on the cable which may exist at the upper end of the housing thereby to maintain the upper end of the housing from tilting relative to the casing. Below the upper housing section **15** is an electronic cartridge assembly or housing section **17** which may include a conventional casing collar locator means (not shown) and a conventional radioactivity detector device or means for detecting naturally occurring radioactivity such as gamma rays.

Below the section **17** is the acoustic section **18** which, for example, may be a tubular, rigid housing constructed of steel. A transmitter section T and a receiver section R are spaced from one another along the length of housing section **18**, and the interval of housing between the transmitter T and receiver R sections is suitably perforated in a manner calculated to interrupt lengthwise extending acoustic energy along the housing **18** between the transmitter and receiver sections. The transmitter T and receiver R sections may, for example, include longitudinally extending slots **19** equidistantly spaced from one another about the periphery of the member **18**; and suitable acoustic transducers (not shown), such as magnetostrictive transducers may be suitably secured relative to the transmitter T and receiver R sections.

The perforations along the length of housing member **18**, for example, may include transverse, generally rectangular slots **19*a*** which are staggered or offset relative to one another lengthwise of the housing so that a straight-line acoustic path lengthwise of the housing is substantially interrupted. The perforations may also include circular shaped openings **19*b*** which are illustrated in FIG. 1 in an intermediate position between the transmitter T and receiver R sections. Openings **19*b*** are symmetrically disposed relative to the length of the housing to receive suitable spacing or stand off plugs **24** which provide a means of spacing the entire assembly a given

distance from the wall to the casing. As shown in FIG. 3, the spacing or stand off plugs **24** may be rubber, grommet-like members which are received in openings **19***b* about the circumference of the housing to provide an overall peripheral coverage to space the housing a given distance from the casing regardless of its relative angular position in the casing.

The function of the tool as thus far briefly described is to obtain, at the surface of the earth, recordings of various measurements plotted against depth. The recording may be more specifically identified as a Gamma Ray Log, (GRL), a Casing Collar Log (CCL), and a Cement Bond Log (CBL).

By Cement Bond Log it is meant that acoustic energy transmitted between an acoustic transmitter and receiver in a cased well bore is measured in a certain manner to provide measurements for obtaining a recorded indication of the quality of cementation. The CBL, as shown in FIG. 2, typically provides a base line indication **32** where the cement is suitably bonded to casing, and where bonding is not present, the signal deviates from the base line **32** to produce typical indications or excursions **33** and **34**. The relative intensity of an excursion **33** or **34** is believed to be indicative of the relative quality of cementation, i.e., the greater the excursion the less likelihood of bonding, or effectiveness of cementation, or the presence of cement.

As shown in FIG. 2, a typical Gamma Ray Log is a plot of the intensity of radioactivity in the earth formations, and the base line **27** of the log would normally indicate the shale zones since shale generally emits more gamma radiation than other type of formations. Excursions **28** and **29** of the Gamma Ray Log suggest formations other than shale and may be correlated with the logs of the formations made prior to the casing of the well bore.

The Casing Collar Log provides suitable indications of the location of the casing collar along the length of the casing. As typically shown in FIG. 2, an indication **30** would denote the presence of a collar in the casing string at the depth of the indication.

Referring now particularly to FIG. 5, the travel path **40** of acoustic energy between the Transmitter and Receiver is illustrated in a simplified form in terms of a ray of energy which travels through the well fluid to the casing, along the casing and returns to the receiver. The intensity of the wave front for the acoustic energy traveling path **40** is dependent upon the degree of coupling of the casing to the material surrounding the casing and the characteristics of the material itself.

In FIGS. 5 and 6 the system for deriving the above-described logs include a surface source or power supply **43** of alternating current which is connected to an insulated monocable conductor **44** wherein the metal sheath **44***a* of the cable **14** forms a ground return. A switch **43***a* is inserted between the power supply **43** and conductor **44** to disconnect the supply **43** from conductor **44** and also to permit the selective connection of either a positive (B+) or negative (B—) source of direct current (D.C.) to the cable conductor **44**. In the position of the switch **43***a* as illustrated, alternating current (A.C.) is supplied via cable conductor **44** to a conventional shaper circuit **42** in the borehole apparatus (FIG. 5). The secondary winding of the transformer **51** interposed between conductor **44** and the shaper circuit **42** does not affect the application of the A.C. signals to the shaper circuit **42** which is arranged to emit pulses to synchronize the master keyer **41** with the A.C. supply. The master keyer **41**, which is a conventional multivibrator of free running type synchronized by pulses from the shaper, triggers the transmitter means **41***a*. The transmitter means **41***a* is arranged in a conventional manner to produce an acoustic impulse in response to the trigger from the keyer circuit **41** which impulse subsequently arrives at the receiver means **47***a*.

The electrical signal or trigger signal from the master keyer **41** which operates the transmitter means **41***a* also triggers a conventional delay circuit **45** which, after a predetermined time, actuates a conventional time gate circuit **46**. The time gate circuit **46**, in turn, controls an amplitude sensitive circuit **47** for a preselected time period so that an electrical output signal is developed which is representative of the peak amplitude of signal appearing at the input of the amplitude circuit **47** during the preselected time period. The amplitude circuit **47** is coupled between the receiver means **47***a* and a low pass filter **48** which serves to perfect or smooth out the output signal of the amplitude circuit **47**. The output signal from amplitude circuit **47** is passed from the filter **48** to an output circuit **49** which is arranged to develop an output signal containing pulses wherein the pulse rate of the output signal is proportional to the amplitude of the peak voltage of the input signal derived from the amplitude circuit **47**. The pulses of the output signal are negative relative to a reference value electrical or ground return and are conducted to the monocable conductor **44** via the primary winding **50** of transformer **51**. The secondary winding **52** of transformer **51** is isolated from the electrical ground return **44***a* by means of a blocking capacitor **53**.

From the foregoing it will be appreciated that, at a predetermined time after the acoustic impulse is emitted by the transmitter means, an electrical signal is generated by the receiver means in response to the arrival of the emitted acoustic impulse; and this signal is sensed by the amplitude circuit **47** over a predetermined time period or interval. In this way each of the successive measurements are related to one another since they are consistently sampled at like or given predetermined times after the emission of acoustic impulses and over like or given predetermined time intervals.

In accordance with the foregoing remarks, if it is desired to measure the characteristic of the signal as it initially arrives at the receiver means, the time may be calculated in a well-known manner by a consideration of the stand off distance of the transmitter means and the receiver means from the wall of the casing, the velocity of the fluids, the angle of incidence between the passage of acoustic energy when it is transmitted via the fluid into the casing, the velocity of the casing and the spacing between the Transmitter and Receiver. Thus, the stand off plugs **25** as disclosed in FIG. 3 now assume their proper significance and importance in providing a given stand off spacing of the tool from the casing so that the preselected time may be determined with a great deal of certainty. After a precise determination of the preselected time has been calculated, the delay circuit **45** may accordingly be set to operate time gate **46** at a time related to the triggering of the transmitter T. Time gate **46** may have an operational time duration set according to a selected time period (which may be determined from the frequency of the emitted acoustic impulse) to measure only the desired portion of the signal.

For one reason or another it may be desired to change the stand off distance of the tool from the casing wall. For example, a centralizer unit **65** (FIG. 4) with circumferentially spaced, elastomer constructed arms **65'** can be coupled to the apparatus to centralize the same in the casing. Moreover, the desired portion of the signal to be measured may typically arrive either before or after the actuation of time gate **46** while the apparatus is in the well bore. In either of these cases, i.e., to accommodate changes in the stand off distance as well as optimize operation of the apparatus, a switching circuit **70** (FIGS. 5 and 7) is connected to the delay circuit **45** and effectively controls the duration of the time delay occurring between the pulsing of the transmitter and the actuation of the time gate circuit **46**. Specifically, the switch circuit **70** varies the time delay in circuit **45** by predetermined increments of time and is operated by a surface control signal trans-

mitted via the monocable conductor **44** in a manner which will hereinafter be more fully explained.

Referring to FIG. 7, the switching circuit **70** for changing the time delay of delay circuit **45** is illustrated in detail. In general, the switching circuit **70** is adapted to be normally inoperative whenever the A.C. power source **43** at the earth's surface (FIG. 6) is coupled to the conductor **44** of the monocable by switch **43***a*; and, as explained heretofore, when the A.C. source is disconnected from the conductor **44** by switch **43***a*, either positive or negative voltage or control signals may be applied to the monocable to effect an operation of the switch circuit **70**. In the particular arrangement hereinafter to be described, a positive D.C. signal or potential serves to step a stepping switch in the switching circuit **70** while a negative D.C. potential or signal serves to reset the aforementioned stepping switch to its starting position. The connections of the various stationary contacts of the stepping switch provide a control effect by varying the time delay characteristics of the delay circuit **45**.

In the switch circuit **70**, a first relay or switch **71** is arranged to be operated by virtue of an A.C. current on the monocable **14** to disconnect an input conductor **44***b* of the monocable conductor **44** from an input conductor **72** in the switch circuit **70**. In the absence of A.C. current in the monocable **14**, conductors **44***b* and **72** are normally connected to one another by a normal closed position of the contacts of switch **71**. Switch **71** has a solenoid **72***b* which is electrically connected between an electrical ground and the downhole D.C. power supply **72***a*. The D.C. power supply **72***a* is coupled via a transformer **71***a* to cable conductor **44** so that the power from the A.C. surface supply **43** is rectified to provide a D.C. output to the solenoid **72***b* as well as provide D.C. outputs or biasing potentials for other downhole circuitry. Hence, when the surface A.C. power supply **43** is connected to conductor **44**, solenoid **72***b* is energized so that switch **71** disconnects the input conductor **72** in the switch circuit **70** from the cable conductor **44***b*.

The delay circuit **45** may be a one shot multivibrator which is illustrated in part in the upper portion of FIG. 7 and includes a resistance **73** and capacitance **74** in a network wherein any change of capacitance in the network will alter the time delay operational characteristics of the multivibrator. As such, the capacitor **74** in the multivibrator may be selectively combined with other capacitors **74** (*a*, *b* . . . *k*) with various selected values to selectively alter the time delay operational characteristics of the delay circuit **45**. The various capacitances **74** (*a*, *b* . . . *k*) may be coupled in parallel to the capacitance **74** by inserting the various capacitors between the respective stationary terminals of a stepping switch **76** and on terminal of the capacitor **74** and connecting the movable arm **77** of the stepping switch **76** to the remaining terminal of the capacitor **74**. The solenoid **78** for operating the stepping switch **76** is coupled to the input conductor **72** via a diode **77***a* which is connected such that a single positive D.C. voltage signal applied to the input conductor **72** is conducted via the diode **77***a* to the solenoid **78**, thereby stepping the switch through one step or one position. Hence, for each applied positive pulse the switch **76** may be stepped one position to distinctively change the time delay by a fixed preselected increment of time.

Should it be desired to reset the switch **76** at any time to the initial or "home" position illustrated in the drawings, the following system is provided. A cam **80** is mechanically coupled (as shown by dashed line **81**) to the movable arm **77** of the stepping switch and controls the position of a mechanism of linkage **82** which in turn controls a relay or switch **83**. Switch **83** has a movable contact coupled to the input conductor **72** which, in the initial position of the stepping switch **76** shown, couples input conductor **72** to a diode **84** and resistance **85** to electrical ground. The diode **84** is so connected that the diode **84** conducts only when the potential on conductor **72** is negative, and the resistance **85** thereupon provides an electrical load. Switch **83** in its other position connects its movable arm and, accordingly, the input conductor **72** to the movable arm of an interrupter switch **86** which in a closed position completes a circuit to the solenoid **78**. Hence, the cam **80** serves to operate the relay switch **83** in a "home" position of the movable arm **77** of the stepping switch **76** to disconnect or break the electrical path from conductor **72** via the interrupter switch **86** to the solenoid **78**.

From the foregoing description it will be appreciated that any time after the cam **80** is stepped one position, the linkage **82** operates switch **83** so that input conductor **72** is connected via switch **83** and interrupter switch **86** to the solenoid **78**. Thus, if it is desired to reset the switch **76** to its initial position, a negative potential can be applied to the input conductor **72** via the cable conductor **44**, which negative potential causes a current flow via switch **83**, interrupter switch **86** and the relay solenoid **78**. Solenoid **78** is then energized to step one position, and in so doing, interrupter switch **86** is opened and closed. The opening of the interrupter switch **86** permits the solenoid **78** to be de-energized while the subsequent closing causes the cycle to repeat. Hence, the stepping switch **76** will be stepped automatically until the cam **80** actuates switch **83** to disconnect the input conductor **72** from interrupter switch **86**. Switch **83** when actuated by cam **80** couples the input conductor **72** to the dummy resistance load **85** via the diode **84**. Since the diode **77***a* in switch circuit **70** prevents further actuation of solenoid **78** of switch **76** by the negative potential, the stepping switch **76** is held in its "home" position. To prevent burning out and sparking of the contact elements of interrupter switch **86**, an arc suppression network **90** may be connected across the switch **86**.

It should also be appreciated that a purpose of disconnecting the solenoid **78** or dummy load **85** from the conductor **44** is to prevent shorting out of the casing collar signals and the pulse signals.

Referring now to FIG. 5, the amplitude circuit **47** which is controlled by a timed pulse output from time gate **46** includes a triode gating tube **90** with its control grid connected to time gate **46** and its plate coupled via a diode **91** to an amplifier **92** which is, in turn coupled to the receiver means **47***a*. The diode **91** is connected in this circuit so that voltage signals are effectively passed to ground via the low impedance path of the triode **90**. Also coupled to amplifier **92** is another diode **93** which is connected to a cathode follower **94**. Between the diode **93** and cathode follower **94** are a resistance **95** and capacitance **96** which are connected to ground. Diode **93** is similarly connected to pass voltage signals from amplifier **92**. The electrical signals generated by the receiver means **47***a* in response to acoustic impulses are passed via the triode **90** to ground by diode **91** since this is a relatively low impedance path. However, when a control pulse from time gate **46** cuts off tube **90**, diode **93** conducts in response to the electrical signal and capacitor **96** is charged up to the attained peak value of the applied voltage. Resistor **95** has a value to hold such an attained peak value for an adequate period of time. The resistor **95** and capacitor **96** are provided with a relatively large time constant and cathode follower **94** accordingly produces an output signal which is proportional to the peak value of the signal applied to diode **93** during the period that triode **90** is non-conducting. It has been considered preferable to measure the peak value of only a half cycle of the electrical signal and, in particular, the second half of the first cycle of the signal.

The voltage output of the cathode follower **94** is filtered or smoothed out by the filter circuit **48** and passed to the output circuit **49** which is arranged to produce a pulse output having a rate proportional to the amplitude of the input signal from the cathode follower **94**.

Output circuit **49** is shown in detail in FIG. 8, and in the diagram the input to output occurs from right to left. For a complete understanding, certain typical waveforms of the operating conditions at various locations in the circuit are illustrated in FIGS. 9 and 10. In the circuit, the input terminals **100** are arranged to receive the D.C. signal from low pass filter **48** which signal is applied via resistances **98** and **99** to the emitter **101** of a PNP transistor **102**. A capacitor **97** is connected across the input terminals **100** to filter A.C. signal components. The collector **104** of transistor **102** is connected via a capacitor **105** to ground. The base **106** of transistor **102** is connected across a resistance load **109** coupled to an emitter **107** of an NPN transistor **108** wherein the collector **110** is connected to a regulated source of positive D.C. voltage and the base **111** is connected to a voltage dividing network comprised of resistances **112** and **113**. This cascaded transistor arrangement permits the voltage drop between the emitter **101** and base **106** of transistor **102** to be balanced by the voltage drop between the base **111** and emitter **107** of the transistor **108**. With the above described arrangement resistances **98** and **99** are made large compared to the input resistance at emitter **101** so that

$$I_{in}=\frac{E_{in}-E_1}{R_1+R_2} \tag{1}$$

where E_{in} represents the input voltage, I_{in} represents the input current, E_1 represents the voltage at the base of transistor **108** and R_1, R_2 represent the resistance values of resistances **98** and **99**. Consequently, the current I_c to the capacitor is equal to the input current I_{in} times the amplification factor α. Capacitor **105** is charged by a constant current α I_{in} and acquires charge, and hence voltage, at a rate proportional to I_{in} and therefore proportional to E_{in}.

Capacitor **105** is connected to a conventional Schmitt trigger circuit **114**. In the quiescent condition of circuit **114**, an input NPN transistor **115** is normally at cut off or "off" while an output NPN transistor **116** is normally conducting or "on". The output conductor **117** of transistor **116** is connected to the base **118** of an amplifying transistor **119** which, in turn, has its emitter **120** connected to the base **121** of another amplifying transistor **119***a*. The collector **123** of transistor **119***a* is connected to the primary winding **50** of the output transformer **51** which has its secondary winding **52** coupled to the monocable **44**. Winding **50** of the transformer **51** is coupled to a D.C. positive potential source.

The output conductor **117** of the Schmitt trigger circuit **114** is also connected via a conductor **122** to the base **124** of a transistor switch **125**. Transistor switch **125** has an emitter **126** connected to ground and a collector **127** coupled via a resistance **128** to the capacitor **105**. Transistor switch **125** has normal operating condition at cut-off or "off".

The operation of the above-described circuit is as follows: at a given time t_o (FIG. 9), the transistor **115** is off, transistor **116** is on and transistor **125** is off. With an applied E_{in}, the voltage E_c on the capacitor **105** will reach a value of E_t equal to the firing voltage of the transistor **115** of Schmitt trigger at a time t_x, which time t_x is proportional to

$$\frac{C}{I_c}\int dE_c \tag{2}$$

where C is the capacitance of capacitor **105**. When transistor **115** "fires," or is turned on, transistor **116** is turned off and transistor switch **125** is turned on. Transistor switch **125** discharges capacitor **105**, with a time constant dependent upon resistance **128** and capacitor **105**, and this time constant is made short compared with the minimum period of an output pulse rate to be used. This time constant can be arranged, for example, so that 50 microseconds elapse before capacitor **105** discharges to

a voltage E_o. Of course, when the input voltage reaches a value of E_o, the transistor **115** of Schmitt trigger **114** is cut off, transistor **116** is turned on and transistor switch **125** is turned off so that the capacitor **105** commences to charge again. With the same input voltage E_{in}, the time in which the capacitor **105** charges up to the trigger voltage of capacitor **105** is constant and hence it will be appreciated that the spacing or repetition rate of the pulses is dependent upon the amplitude of the input voltage. This is clearly evident from a consideration of FIG. 10 which corresponds to the diagram of FIG. 9 except that a greater slope occurs in the voltage buildup on capacitor **105** between times t_a and t_b indicating a higher input voltage E_{in} which permits a faster charging of the capacitor C_{105}. The output pulses **130** of transistor **116** of the Schmitt trigger **114** thus have a fixed pulse width and a repetition rate dependent upon the amplitude of the input voltage. The period T of the output voltage of the transistor **125** is inversely proportional to the input voltage E_{in}, or, stated another way, the frequency of the output voltage of transistor **125** is equal to

$$\frac{1}{T}\propto E_{in} \tag{3}$$

The output signal supplied to the monocable conductor **44** may be detected in terms of the pulse rate which is proportional to the D.C. input voltage E_{in}, or the output signal can be translated to a D.C. output signal inversely proportional to the input voltage E_{in}.

Returning now briefly to FIG. 5, the gamma ray detector means may consist, for example, of a conventional scintillation counter **140** which detects the existing level of radioactivity and provides an output to a conventional discriminator circuit **141**. A conventional scaler circuit **142** may be inserted between the discriminator circuit **141** and a conventional blocking oscillator output circuit **143** to conform the output of the discriminator circuit **141** to a more convenient form for cable transmission. The output of the blocking oscillator circuit **143** is coupled via a transformer **144** to the monocable conductor **44**. The output of the gamma ray detector means is typically an outyput of positive pulses wherein the repetition rate of the pulses provides an indication of the intensity of the radiation.

The conventional casing collar locater **150** as illustrated is connected via a conventional amplifier **151** to the monocable and provides typically a D.C. signal whose amplitude varies at a low frequency rate in response to the detecting coil of the collar locater **150** traversing a jointed connection in the pipe string. To prevent shorting out the low frequency casing collar signal, blocking capacitors **53**, **152** and **152***a* (FIG. 5) are inserted between the conductor **44** of the monocable and the ground return.

As shown in FIG. 6, at the surface of the earth there are essentially three signals which may be arriving either simultaneously or independently relative to one another. These signals are the D.C. casing collar signal, the positive pulses from the gamma ray signals, and the negative pulses of the acoustic logging apparatus. A conventional galvanometer in a recorder **155** at the earth's surface is made responsive to the casing collar signals to the exclusion of the pulses from the gamma ray and acoustic circuit by suitable filtering so that the signals indicative of the occurence of casing collars may be recorded on the Casing Collar Log developed by the recorder. The positive and negative pulses of the radioactivity and acoustic circuits in the down hole apparatus are supplied to a filter circuit **160** wherein the secondary winding **161** of the transformer **162** has its end terminals **161***a*, **161***b* respectively coupled to conventional detector circuits **162***a*, **162***b*. One of the detector circuits **162***a* is arranged to be responsive to only positive pulses while the other detector circuit **162***b* is arranged to be responsive only to negative pulses. The pulse generators **163***a* and

163*b* serve to reshape the pulses at the outputs of the detectors 162*a* and 162*b*, respectively. The output of detector 162*a* is coupled to the pulse generator 163*a* and also to a gate circuit 164*a*. The gate circuit 164*a* is arranged to be responsive to an output of detector 162*a* to turn off detector 162*b* for a given period of time. Hence, if a positive pulse is detected first by the detector 162*a*, the gate 164*a* would turn off the detector 162*b* for a given time interval. The output of the pulse generator 163*a* is supplied to a counter circuit 165*a* which produces an output voltage representative of the number of pulses per second, which output voltage is supplied to the recorder 155. The output of detector 162*b* is similarly coupled to the pulse generator 163*b* and also to a gate circuit 164*b*. The gate circuit 164*b* is arranged to be responsive to the output of detector 162*b* to turn off the other detector 162*a* for a given period of time. Hence, if a negative pulse is detected first by the detector 162*b*, the gate 164*b* would turn off the detector 162*a* for a given time interval. The output of the pulse generator 163*b* is supplied to a counter circuit 165*b* which produces an output voltage representative of the number of pulses per second which output voltage is supplied to the recorder 155.

The operation of the apparatus from the foregoing detailed description may be readily appreciated; and, therefore, only a brief description hereafter is provided by way of summary of the more pertinent aspects of the present disclosed invention. In operation the apparatus 10 is lowered in the usual manner to the lowermost depth from which the logging operation is commenced. Thereafter, at this depth the switch 43*a* at the surface is connected to the A.C. power source 43 so that the signals are sent down the cable conductor 44; and the keyer means 41 periodically pulses the transmitter to emit time spaced acoustic impulses. Since the stand off device of the apparatus physically spaces the apparatus a given distance from the wall of the casing, the time of arrival of an emitted acoustic impulse at the receiver means 47*a* can be calculated. Since the emitted acoustic impulse normally consists of a number of cycles of undulating pressure waves, the receiver means 47*a* will respond to the pressure waves to produce a corresponding electrical signal. In accordance with a preferred operation of the present invention, it is desired to measure only a single pressure peak which, of course corresponds to single peak of the electrical signal. The pressure peak to be measured is preferably the second peak of the first cycle of an acoustic impulse to arrive at the receiver means 47*a*. Because the time at which such a second peak will arrive at the receiver means 47*a* can be precisely calculated, the amplitude circuit means 47 is actuated at a predetermined time after emission of an acoustic impulse for a predetermined time interval. The timing function for circuit means 47 is accomplished by a delay means 45 and time gate 46 which are connected between the transmitter means and the amplitude circuit 47 which is connected to the receiver means. The amplitude of the electrical signal thus sensed by amplitude circuit means 47 is converted into a pulse by output circuit 49 which pulse output has a relatively negative polarity with respect to a reference level and which pulse output has a repetition rate dependent upon the amplitude of the peak of the signal which was sensed. The negative pulses are passed up cable conductor 44 to trigger a detector 162*b* (FIG. 6) which promptly switch off a positive pulse channel detector 162*a* and counts the number of pulses and applies a signal to the recorder 155 indicative of the amplitude of the signal detected in the bore hole by the receiver means 47*a*. From experience it will generally be known what the amplitude of the signal should be in a casing in which the cement is properly bonded thereto; and while the apparatus is thus resting in the lowermost position of the borehole, such an indication should substantially be reproduced by the recorder.

If, however, the amplitude indication initially obtained is not precisely the indication which might be expected, the accuracy of the reading may be checked by changing the predetermined time delay in the following manner: Switch 43*a* is moved to disconnect the A.C. power source 43 from the cable conductor 44 which immediately disconnects the transmitter means 41*a* and the power supply 72*a* in the borehole apparatus and accordingly discontinues the supply of downhole output potentials from the power supply 72*a*. Thus, the solenoid 72*b* of the switch 70 in the borehole apparatus (which is connected to the output of the power supply 72) is de-energized to permit the switch 71 to assume the position shown in FIG. 7 connected the cable connector lead 44*b* to the input conductor 72 in the switch 70. Now switch 43*a* at the surface may be moved to connect the source of potential B+ to the cable conductor 44 at which time a control signal passes down the cable conductor 44 via the switch 71 and diode 77*a* to actuate a solenoid 78 to step the stepping switch 76 one position. In the "home" position shown in the drawings, a cam 80 simultaneously moved with the movable arm 77 of switch 76 connects the input conductor 72 via a switch 83 and an interrupter switch 86 to the solenoid 78. The stepping of the switch 76 effectively changes the capacitance in a one-shot multivibrator delay circuit 45 so that the predetermined time at which the time gate 46 is actuated has been changed by an incremental period of time. Next, the A.C. power source 43 can again be connected to the cable conductor 44 to operate the transmitter means 41*a* and the downhole power supply 72*a* is again actuated to operate solenoid 72*b* to disconnect, by means of switch 77, the switching circuit 70 from the cable conductor 44. With the transmitter means 41*a* again emitting impulses, the recorder will as previously described produce an indication of the amplitude signal obtained at the predetermined time and during the predetermined time after the emission of each pulse. The above-described operation may be repeated by disconnecting the power supply 43 and applying a positive control signal at the surface to move the stepping switch to another position. At any time, should it be desired to return the stepping switch to its initial "home" position, the switch 43*a* at the surface may be connected to a negative source of potential and this control signal passed via cable conductor 44, the switch 71 and switches 83 and 86 to the solenoid 78. The stepping switch 76 will be continuously actuated as long as the negative source of potential is applied by virtue of the interrupter switch 86 continuously providing the interruption necessary to energize and de-energize solenoid 78 and step the switch. At the time the movable arm 77 of the stepping switch 76 approaches its "home" position, the cam 80 actuates a linkage 80 to disconnect the circuit through the interrupter switch 86 by opening the switch 83 and connecting the negative source of potential to a dummy load 85 in the switch circuit. Switch 83 when open disconnects the solenoid 78 from being operated by the negative potential signal and the switch thus stops in the "home" position. It will be appreciated that although a stepping switch and solenoid are specifically disclosed as operated by the switch 71, the principle involved in the surface control of switch 71 by the circuit 72*a* is applicable to any type of downhole circuit means which may be substituted for the stepping switch and solenoid 78 and selectively operated by a signal which does not actuate circuit 72*a*.

At the same time that the acoustic probing means above described are probing the material surrounding the well bore with the acoustic impulses and providing a pulse output with a given polarity to the common cable conductor 44, a scintillation counter 140 which detects radioactivity in the adjacent surrounding media provides a pulse output which is positive with respect to a reference value. The pulse output of the radioactivity means is also applied to the common cable conductor. Hence, both positive and

negative pulses with respect to a common reference value are supplied to a common cable conductor. Also imposed upon the common cable conductor are casing collar signals which occur only when the device traverses a jointed section between the casing where the changes in the ferromagnetic configuration of the pipe string causes the casing collar locator to produce a low frequency output signal which is also supplied to the common cable conductor **44**. At the earth's surface (FIG. 6) the outputs are individually used to develop the individual log presentations as illustrated in FIG. 2.

As shown in FIG. 8 the amplitude to pulse converter uses a well-known Schmitt trigger circuit **114** in a unique arrangement to provide relatively small time duration pulses, i.e. about 50 microseconds with a repetition rate dependent upon the input amplitude. In this arrangement a constant current source is used to charge a capacitor which thereby provides the signal for triggering the Schmitt circuit. A transistor switch is connected to a resistance discharge path and operated upon the triggering of the Schmitt circuit to rapidly discharge the capacitor to turn the Schmitt circuit off again.

The foregoing described features are illustrative of a unique system of acoustic logging both singly and in combination with other systems to provide output pulses suitable for single conductor transmission, unique systems of controlling downhole circuit systems coupled to a single conductor, and unique systems of developing output pulses with a repetition rate dependent upon input amplitudes.

While a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. In a well logging apparatus adapted to be suspended below the earth's surface in a well bore by a cable including a single transmission conductor, a control function circuit operable by signals transmitted from the surface over the conductor, comprising first circuit means responsive to first signals on the conductor for developing first output signals, second circuit means having an input connectable to the conductor and responsive to second signals on such conductor for developing control function signals, and switch means connected between the input of said second circuit means and the conductor, said switch means being responsive to said first output signals to actuate said switch means to selectively decouple the second circuit means from the conductor.

2. In a well logging apparatus adapted to be suspended below the earth's surface by means of a monocable in a well bore, a control function circuit operable by signals transmitted from the surface over the monocable, comprising circuit means responsive to first signals on the monocable for developing first output signals, stepping switch means including an actuator responsive to second signals on the monocable for providing various connections between movable and stationary contacts, and switch means connected between the actuator of said stepping switch means and the monocable and responsive to said first output signals to actuate said switch means to decouple the stepping switch means from the monocable.

3. In a well logging apparatus adapted to be suspended beneath the earth's surface by means of a monocable in a well bore, a control function circuit operable by signals transmitted from the surface over the monocable, comprising a switching circuit responsive to D.C. control signals on the monocable for developing a control function, circuit means responsive to an A.C. signal on the monocable for developing an output signal, and switch means connected intermediate said switching circuit and the monocable and responsive to said output signal for controllably decoupling said switching circuit from the monocable.

4. In a well logging apparatus adapted to be suspended beneath the earth's surface by means of a monocable in a well bore, a control function circuit operable by signals transmitted from the surface over the monocable, comprising a switching circuit responsive to D.C. control signals on the monocable for developing a control function, rectifier means responsive to an A.C. signal on the monocable for developing a D.C. output potential, and switch means connected between said switching circuit and the monocable and responsive to the D.C. output potential for controllably decoupling said switching circuit from the monocable.

5. In a well logging apparatus adapted to be suspended beneath the earth's surface by means of a monocable in a well bore, a control function circuit operable by signals transmitted from the surface over the monocable, comprising: a switching circuit including a solenoid operated stepping switch responsive to D.C. control signals on the monocable for developing a control function, a reset switch and an interrupter switch connected in a series circuit with said solenoid, said interrupter switch being operable by said stepping switch to cause said stepping switch to advance a predetermined number of steps for each application of a D.C. control signal of given polarity on the monocable, said reset switch interrupting said series circuit when the stepping switch is in a predetermined position, and a diode connected between the input of said reset switch and said solenoid to bypass said switches while a D.C. control signal of an opposite polarity is applied to the switching circuit; rectifier means responsive to an A.C. signal on the monocable for developing a D.C. output potential; and switch means connected between said series circuit and the monocable and responsive to said D.C. output potential to decouple said switching circuit from the monocable.

6. An electrical system for converting an analog signal into a digital signal including: circuit means having an input and output and operable to develop a pulse output; current storage means coupled to said input to provide an input trigger signal upon charging up to a predetermined value; selectively operable discharge means coupled to said current storage means and responsive to a pulse output signal from said circuit means to discharge said current storage means.

7. An electrical system for producing output pulses at a rate proportional to an input current signal including, a trigger circuit for providing an output pulse in response to an input signal exceeding a given voltage magnitude, storage means coupled to said trigger circuit and adapted to be charged by a current signal to provide an input voltage signal for said trigger circuit, and discharge means coupled to said storage means and said trigger circuit and operable in response to an output pulse to discharge said storage means.

8. An electrical system for producing output pulses at a rate proportional to a current signal including a trigger circuit for providing an output pulse of constant width and constant amplitude in response to an input signal exceeding a given voltage magnitude, storage means coupled to said trigger circuit and adapted to be charged by a current signal to provide an input signal for said trigger circuit, means for providing a constant current signal to said storage means, and discharge means coupled to said storage means and said trigger circuit and operable in response to an output pulse to discharge said storage means.

9. An electrical system for producing output pulses at a rate proportional to a current signal including a Schmitt trigger circuit for providing an output pulse of constant width and constant amplitude in response to an input signal exceeding a given voltage magnitude, storage means coupled to the input of said trigger circuit and adapted to be charged by a current signal to provide an input

signal for said trigger circuit, means coupled to the input of said storage means to provide a constant current signal to said storage means, and discharge means coupled to said storage means and said trigger circuit and operable in response to an output pulse to discharge said storage means.

10. The apparatus of claim **9** wherein said discharge means includes a resistance and a normally non-conducting switch device, said switch device being operative in response to an output pulse to discharge said storage means.

11. In a well logging apparatus adapted for suspension in a well bore by a single cable conductor, a system for controllably generating a pulse output representing an analog signal, comprising: first circuit means responsive to first signals on the conductor for developing first output signals; second circuit means responsive to second signals on the conductor for developing a control function; switch means connected between the input of said second circuit means and the conductor and being responsive to said first output signals for selectively coupling and decoupling said second circuit means from the conductor; gating means responsive to said control function to provide gating pulses in variable time relation to the occurrence of an amplitude signal; means responsive to the amplitude signal and to said gating pulses to provide an analog signal representative of the strength of said amplitude signal within the time duration of said gating pulses; and analog to digital converting means including pulse circuit means having an input and output and operable to develop a pulse output, storage means responsive to said analog signal and coupled to said input to provide an input trigger signal upon charging up to a predetermined value, and selectively operable discharge means coupled to said storage means and responsive to a pulse output signal from said pulse circuit means to discharge said storage means.

12. Apparatus in accordance with claim **11** wherein said means responsive to the amplitude signal includes voltage storing means responsive to said amplitude signal for storing a voltage signal proportional to the maximum amplitude of said amplitude signal occurring within the time interval of one of said gating pulses, and means responsive to said voltage signal to produce said analog signal.

13. In well logging apparatus adapted to be suspended by a monocable in a well bore beneath the earth's surface, a variable pulse width generating system operable by signals transmitted from the surface over the monocable, comprising: pulse generating means for generating variable time width pulses in synchronism with first signals on the monocable and including timing circuit elements determinative of the pulse time width; switching means responsive to control signals on the monocable for selectively switching different-valued elements into said timing circuit; and circuit means responsive to said first signals on the monocable for rendering said switching means unresponsive to said control signals when said first signals are present.

14. Apparatus as defined in claim **12**, wherein said circuit means comprises a switch connected intermediate the monocable and said switching means, and means responsive to said first signals only for actuating said switch to disconnect said switching means from the monocable.

15. In a well logging apparatus adapted to be suspended by a monocable in a well bore beneath the earth's surface, a control function circuit operable by signals transmitted from the surface over the monocable, comprising: a switching circuit including actuator means operative to complete a successive one of a number of electrical connections in response to each application of a first control signal on the monocable, said switching circuit also including means responsive to each application to the monocable of a second control signal distinctive from said first signal for causing the selection by said actuator means of a predetermined one of said electrical connections; circuit means responsive to third signals on the monocable for developing a third control signal; and switch means connected between the actuator means of said switching circuit and the monocable and operable by said third control signal for selectively rendering the switching circuit responsive and unresponsive to said first and second control signals.

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