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(54) ELECTRONIC BLAST CONTROL SYSTEM FOR MULTIPLE DOWNHOLE OPERATIONS

(76) Inventor: Otis R. Anderson, Houston, TX (US)

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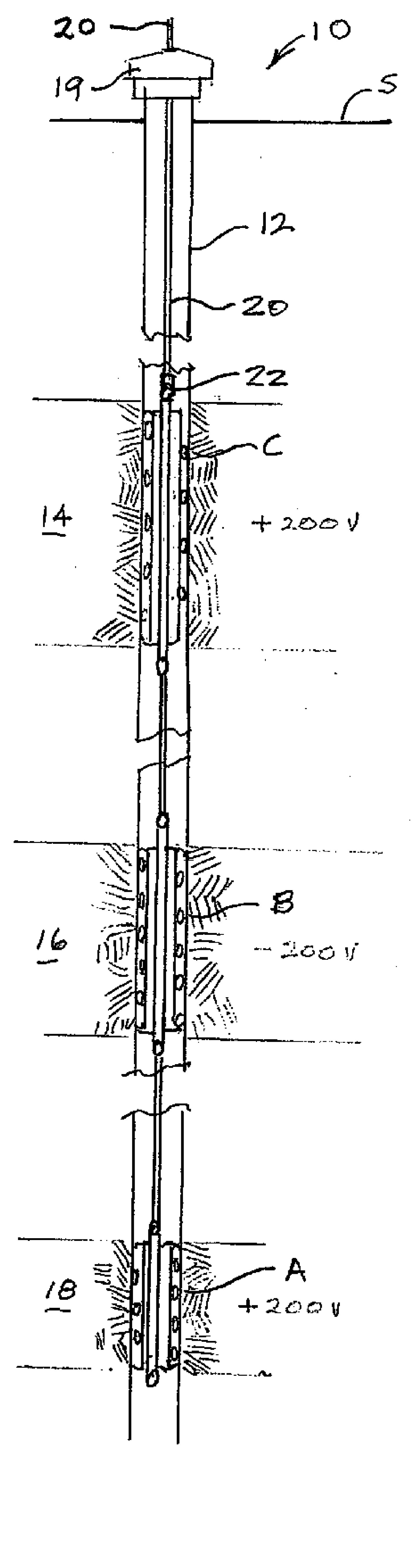
(57) ABSTRACT

A system for multiple subsurface operations which are carried out in a well bore by means of two or more well tools having explosive or gas generating charges which are electronically initiated for accomplishing any number of other downhole well activities. Two or more well service tools are simultaneously run into a well on a single wire-line and are located at predetermined positions. An electronic blast control system having safety parameters, including time, movement, pressure and the like to ensure safe running and independent firing of the tools. The blast control system permits controlled energization of the explosive charges only when all of the programmed parameters have been met and causes sequential or serial electronic firing of the explosive devices independently of one another by positive and negative voltages.



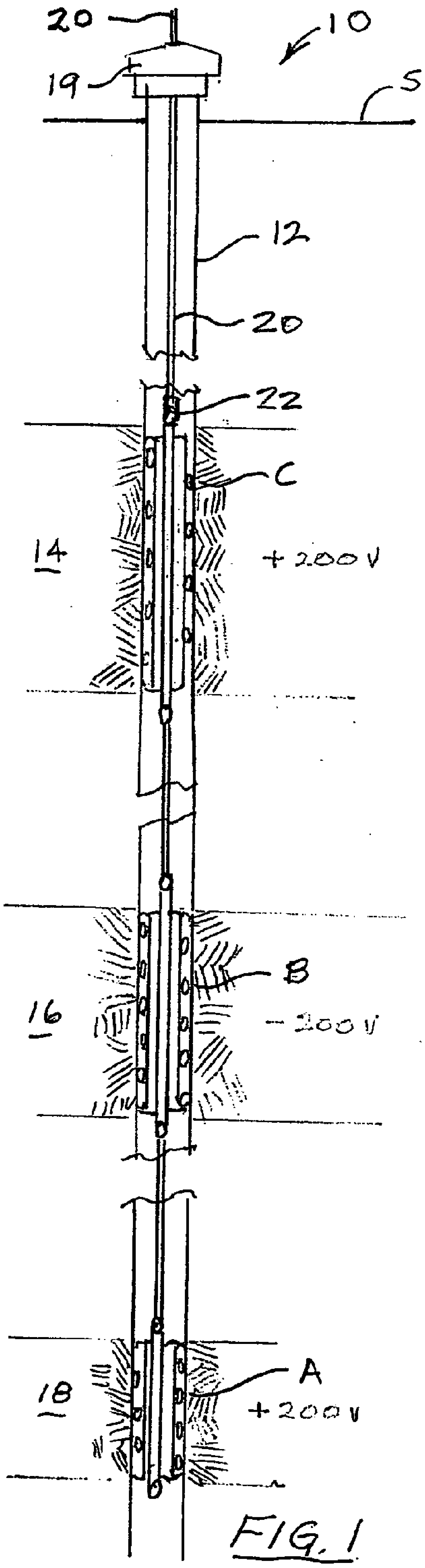

20
10
19
S
12
20
22
C
14
+200V
B
16
-200V
A
18
+200V

FIG. 1

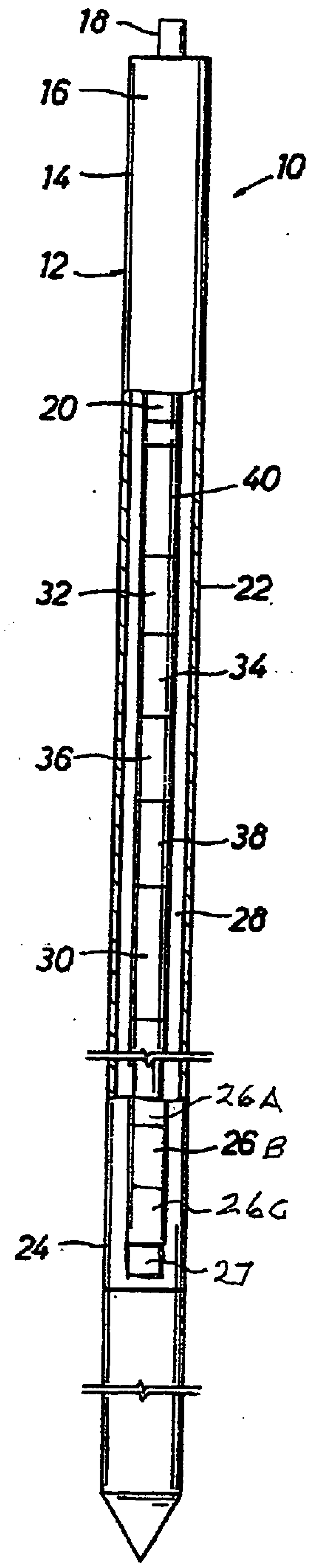

18
16
14
10
12
20
40
32
22
34
36
38
28
30
26A
26B
26C
24
27

FIG. 2

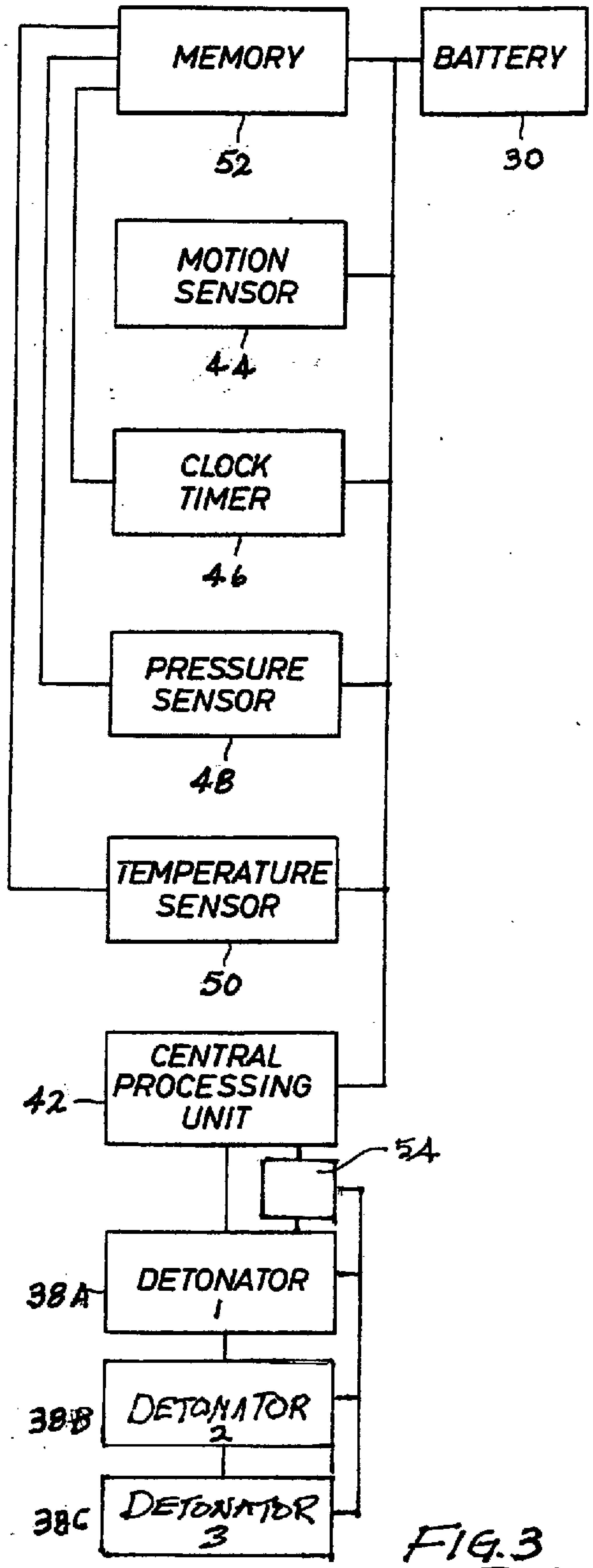

MEMORY
52
BATTERY
30
MOTION SENSOR
44
CLOCK TIMER
46
PRESSURE SENSOR
48
TEMPERATURE SENSOR
50
CENTRAL PROCESSING UNIT
42
54
DETONATOR 1
38A
DETONATOR 2
38B
DETONATOR 3
38C

FIG. 3

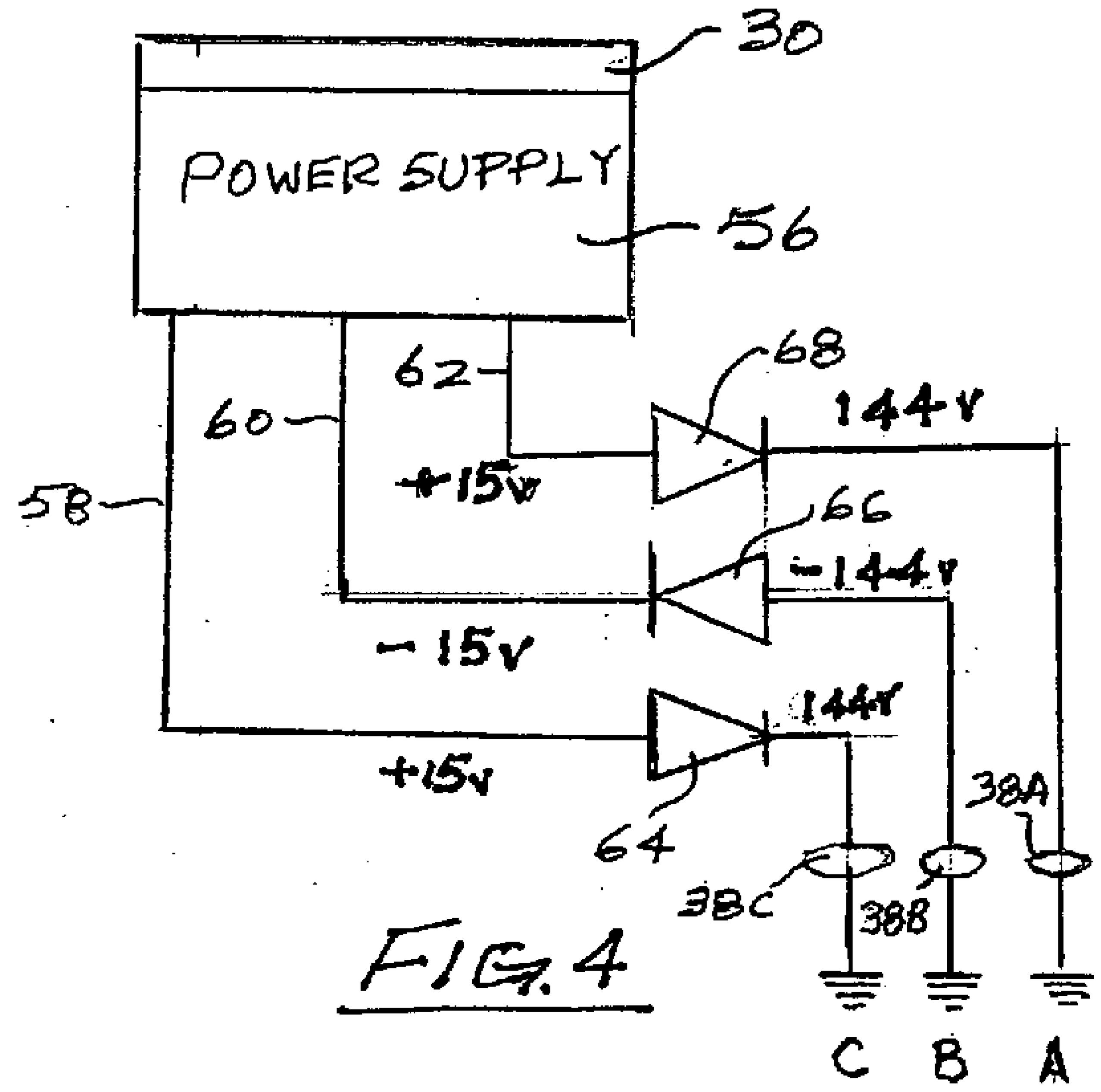

30
POWER SUPPLY
56
62
68
60
58
+15v
144v
66
-144v
-15v
144v
+15v
64
38A
38C
38B
C
B
A

FIG. 4

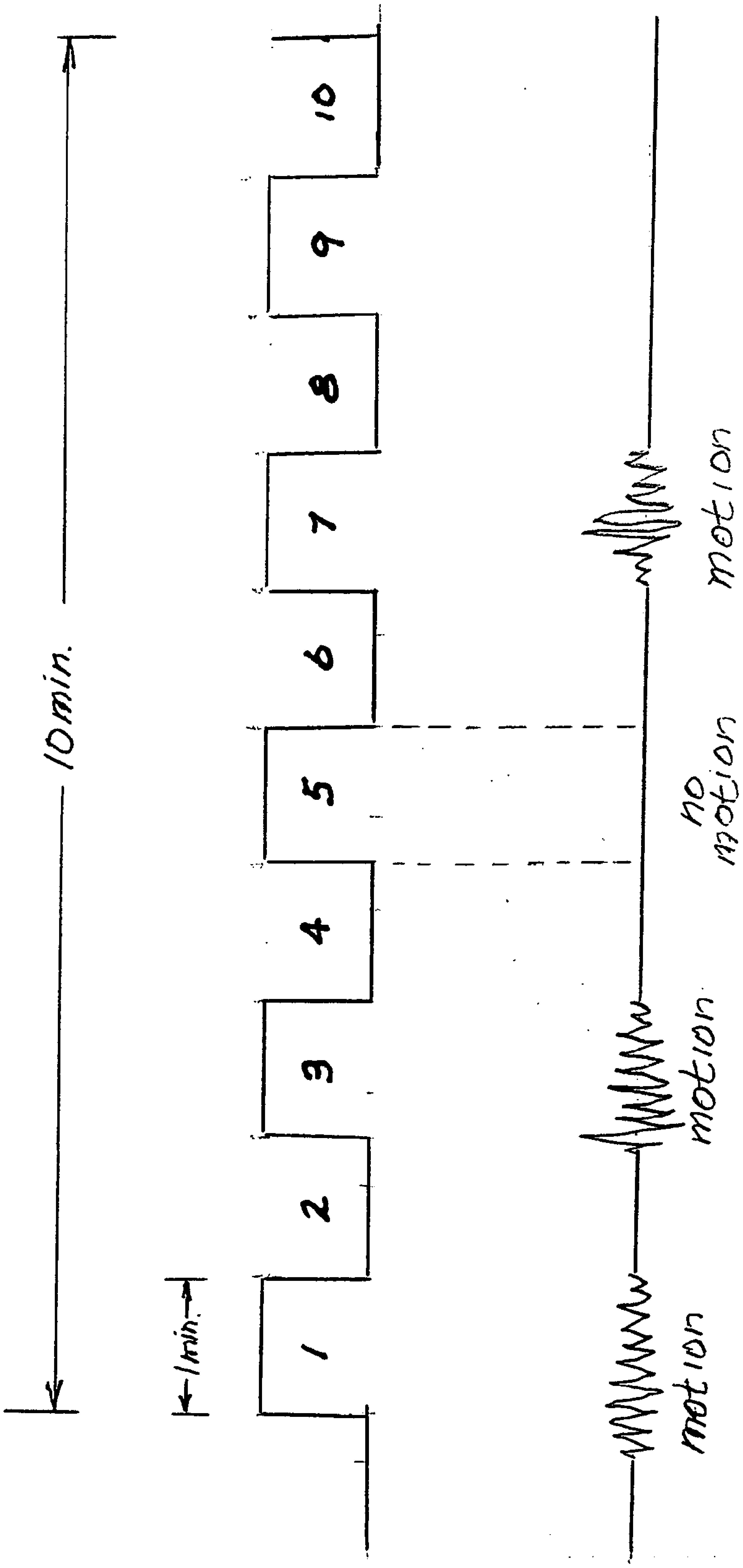


FIG. 5

ELECTRONIC BLAST CONTROL SYSTEM FOR MULTIPLE DOWNHOLE OPERATIONS

RELATED PROVISIONAL APPLICATION

[0001] Applicant hereby claims the benefit of U.S. Provisional Patent Application No. 61/399,091 filed on Jul. 7, 2010 by Otis R. Anderson and entitled "Electronic Blast Control System For Multiple Downhole Operations", which Provisional Patent Application is incorporated by reference herein for all purposes.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates generally to subsurface operations which are carried out in a well bore by means of one or more spaced explosive charges which are typically contained within spaced blast joints or blast guns and are electronically initiated for doing such work as perforation of well casing by means of shaped charges, setting of packers by means of explosive generated pressure, and for sequentially accomplishing any number of other downhole well activities. More specifically, the present invention concerns a method and apparatus for electronically controlling well service operations for two or more well service tools that are simultaneously run on a wire-line to ensure safe and timely sequential or serial operations such as casing perforation. Even more specifically, the present invention concerns safely positioning explosive type well tools at selected predetermined depths within a well bore or well casing and safely and sequentially electronically firing the explosive devices independently of one another to achieve the intended work. The present invention concerns the use of a positive voltage for controlling firing of one typically lower well tool and negative voltage for controlling firing of an adjacent, typically upper well tool so that the firing of a well tool will not cause unintentional firing of or damage to another well tool.

[0004] 2. Description of the Prior Art

[0005] Since the handling of explosives is an inherently dangerous activity, for the protection of personnel and equipment from the adverse effects of undesired explosive detonation it is highly desirable to provide a firing control system that permits firing of the explosive charges of a single perforating gun or those of two or more spaced perforating guns only under strictly controlled circumstances. It is imperative that a downhole explosive device be permitted to fire only when it is properly located at designed depth within the well; otherwise, the well casing could be perforated at the wrong depths or well service personnel could experience significant danger.

[0006] Electronic blast control systems have been developed for actuation of explosive charges within wells for doing work, such as perforation of well casing, setting of packers and various other downhole activities requiring significant energy. Some electronic blast control systems are initiated from the surface via an electric line for electrical supply and control. Other electronic blast control systems are conveyed on wire-line and employ battery power and electrical charge pumping to convert battery voltage, such as 12 volts to a charge firing voltage on the order of 200 volts. Though blast control systems having electric line supply and control are used, such systems are quite expensive and difficult because of the necessity for providing electrical supply and control lines extending from the surface to the depth for the downhole activity, which is typically near the bottom of the well. It is therefore desirable to provide a novel electronic wire-line conveyed blast control system that ensures that a downhole explosive device which fails to fire or is not fired for any number of reasons can be efficiently and safely retrieved from the downhole environment without compromising the safety of the well equipment or the well personnel at the surface.

[0007] More recently, electronic blast control systems have been developed for actuation of explosive charges within wells for doing work, such as perforation of well casing, setting of packers and various other downhole activities requiring significant energy. Some electronic blast control systems are initiated from the surface via an electric line for electrical supply and control. Other electronic blast control systems are conveyed on wire-line and employ battery power and electrical charge pumping to convert battery voltage, such as 12 volts to a charge firing voltage on the order of 200 volts. Though blast control systems having electric line supply and control are used, such systems are quite expensive and difficult because of the necessity for providing electrical supply and control lines extending from the surface to the depth for the downhole activity, which is typically near the bottom of the well. It is therefore desirable to provide a novel electronic wire-line conveyed blast control system that ensures that a downhole explosive device which fails to fire or is not fired for any number of reasons can be efficiently and safely retrieved from the downhole environment without compromising the safety of the well equipment or the well personnel at the surface.

[0008] Under circumstances where a wellbore intersects two or more production zones it is typically necessary to perforate the well casing at each of the zones. According to present practices it is necessary to independently run a perforating gun into the well for each zone. A perforating gun is run into the well by wireline and is typically located at the bottom production zone. The perforating gun is then fired, preferably according to the method and using the apparatus that is set forth in U.S. Pat. No. 5,369,579 of Otis R. Anderson. After the first perforating job has been completed, another perforating gun is then run into the well by wireline and is positioned at a production zone that is above the lower production zone and is electronically initiated in similar fashion. This process is continued for as many production zones as are intersected by the wellbore. Independently running a number of well tools into a well in this fashion is an expensive proposition due to the significant rig time and labor costs that are involved. It is desirable therefore, to provide for running a plurality of well tools into a well with a single tool running operation and then initiating the well tools sequentially, while at the same time protecting the well tools against inadvertent simultaneous initiation.

SUMMARY OF THE INVENTION

[0009] The subject matter of the present invention is directed generally to blast control systems for perforating guns that are employed to perforate well casing at the depths of two or more production formations or zones that are intersected by the wellbore. This electronic blast control system is controllable so as to safely permit sequential or serial firing of casing perforation charges or other sequential electronically activated events at different formation depths within a well. However, it is understood that the present invention concerns the controlled activation or firing of explosive or gas-generating charges in the downhole environment for the performance of a variety of tool activations, including setting or releasing packers or anchors or to actuate other mechanical or electromechanical devices. The term "blast control", as specified in this invention disclosure, is therefore not intended to limit the spirit and scope of the present invention to any particular downhole service activity, but rather is employed to indicate the activation of sequential or serial downhole activities that are controlled by an on-board programmable electronic memory.

[0010] It is a principal feature of the present invention to provide a novel blast control system that is capable of selectively and sequentially activating or firing two or more well service tools that are simultaneously run into a well by a single tool conveying system such as a wire-line tool conveyor, a coiled tubing tool conveyor, a conduit type tool conveyor or any other conveyance system that is in use at the present time.

[0011] It is another feature of the present invention to provide a novel blast control system for a plurality of well service tools, such as casing perforation guns, whereby the tools are run into the well or wall casing in an un-armed state and the arming and firing of an initial well service tool accomplishes arming and subsequent firing of a sequential well service tool, and so on until all of the well service tools have been individually fired and firing success has been confirmed.

[0012] It is also a feature of the present invention to provide a novel blast control system having an electrical power supply including a storage battery and processing circuitry for providing positive and negative firing voltage that is selectively connected with individual detonators or other apparatus so that adjacent well service tools cannot be fired simultaneously or out of sequence by any particular voltage.

[0013] It is another feature of the present invention to provide a novel blast control system for multiple well service tools that require the firing of one well service tool to accomplish arming of another well service tool before that tool can be fired under the control of the blast control system.

[0014] Briefly, the various objects and features of the present invention are realized through the provision of U.S. Pat. No. 5,369,579 of Otis R. Anderson is incorporated by reference herein for all purposes. Many of the features of the '179 patent will be employed together with the features of the present invention to provide a multi-shot downhole well servicing operation wherein two or more tools are run into a well casing simultaneously by wireline equipment, typically known as "slick line" and are activated sequentially. This blast control system is primarily designed for serial energization or firing of spaced series related perforating guns; however it is not intended that the present invention be limited solely to perforating guns. Other downhole activities in wells, such as setting packers and anchors or cutting well casing can also be performed in a manner that takes advantage of running tools into a well a single time for the conduct of multiple downhole activities that utilize explosive generated gas pressure or explosive actuation of components. When the multi-shot tools are in the form of casing perforation guns each having multiple shaped charges, the perforation guns are run into the well in the same run and are each positioned at a designed depth. The perforation guns are activated responsive to voltage of designed polarity, positive or negative, and adjacent perforation guns or other well service tools are responsive to voltage of the opposite polarity. The reversed polarity voltage is achieved by reversing circuit diodes that permit the flow of boosted battery power from a battery supply that is on board the instrument or tool of the blast control system. Obviously, in the case of wells, the first tool of a spaced series of tools will be actuated by voltage of a selected polarity, positive or negative. The next succeeding tool will be actuated by voltage of opposite polarity, negative or positive, thus ensuring against detonation or energization of adjacent well service tools.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] So that the manner in which the above recited features, advantages and objects of the present invention are attained and can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the preferred embodiment thereof which is illustrated in the appended drawings, which drawings are incorporated as a part hereof.

[0016] It is to be noted however, that the appended drawings illustrate only a typical embodiment of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0017] In the Drawings:

[0018] FIG. **1** is a partial sectional view of a well intersecting three production formations and showing three well tools, such as perforating guns, being located in relation with the depths of the production zones by a single wireline during a single run of a plurality of well service tools;

[0019] FIG. **2** is a partial sectional view showing a multi-shot well service tool for sequential actuation or firing of the well service tools of FIG. **1**;

[0020] FIG. **3** is a block diagram electronic schematic illustration showing the various electronic components of the multi-shot well service tool of FIGS. **1** and **2**;

[0021] FIG. **4** is a partial electronic schematic illustration showing the use of positive and negative amplified voltage for sequentially firing the well service tools of FIG. **1**; and

[0022] FIG. **5** is a graphical illustration of a timing sequence and running motion pattern of ten minutes that is employed to establish parameters that must be met for well service tool activation according to the principles of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

[0023] The term "blast control" as used herein is intended to mean a control system for two or more electronically initiated and sequentially activated devices that develop an explosive force or rapid generation of combustion gas in the downhole environment for the purpose of doing desired work. The work may take the form of casing perforation by sequential or series explosive shaped charges that develop specifically oriented hot gas jets for perforation of well casing or make take the form of packers, anchors and the like which are activated to set positions by explosive generation of gas.

[0024] Referring now to the drawings and first to FIG. **1**, a well for production of petroleum products such as crude oil and natural gas is shown generally at **10** and incorporates a well casing **12** that lines a borehole intersecting a plurality of subsurface production formations **14**, **16** and **18**. The well casing is connected with a wellhead **19** which extends above the surface "S". Though not shown, a wireline service mechanism having a wireline lubricator will be mounted to the wellhead in conventional to cause controlled wireline running of the tools and to ensure sealing of the wireline against undesired pressure release as the wireline enters the wellhead and casing. To complete the well for production of fluids from the subsurface formation it is necessary to perforate the well casing at each production formation level to permit the well fluids to flow from the formations into the casing via the casing perforations.

[0025] While perforating guns are well service tools that are used for completion of most wells it is not intended to limit the spirit and scope of the present invention to perforating guns, it being understood that other downhole well service tools, such as packers, anchors, and other equipment may be run into a well casing together and selectively actuated in sequential manner via the use of the method and/or apparatus of the present invention. As mentioned above, perforation of well casing for completion of multiple subsurface production zones typically requires multiple service tool runs, one for each perforating gun, because explosive firing of a perforating gun might cause premature firing of another perforating gun. Though individual running of several perforating guns is an expensive and time consuming proposition, for the sake of safety in almost every case each perforating gun is run, positioned at a desired formation depth and is fired for casing perforation. Typically the first of the perforating guns is fired at the lowermost formation depth and subsequent perforating guns are located and fired at the next higher formation depth since firing a perforating gun can leave obstructions within the casing that might interfere with the running of well service tools to deeper depths.

[0026] According to the method and using the apparatus of the present invention two or more well service tools, such as casing perforating guns are run simultaneously by a single wireline running tool and are individually located at desired formation depths within the casing. The perforating guns will not be permitted to fire until a complete set of parameters have been met, as discussed below. When explosive charge firing parameters have been met, only the lowermost perforating gun will be permitted to fire and its firing is necessary to arm the next perforating gun above, before that gun will be permitted to fire. Firing of the second well service tool causes arming of the third well service tool, thus enabling the third well service tool to be fired, and so on until all of the well service tools have been sequentially fired.

[0027] As shown in FIG. **1** three well service tools, perforating guns “A”, “B” and “C” have been located at lower, intermediate and upper production formation depths by a single wireline **20** via a single wireline running tool **22**. Each of the perforating guns is provided with a plurality of spaced and strategically oriented shaped perforating charges of explosive composition that, when fired, will develop a concentrated high temperature explosive jet that will penetrate the well casing and the surrounding cement and in most cases penetrate a short distance into the production formation. The perforating guns will be fired sequentially, starting with the lowermost gun A. Firing of perforating gun A will generate a pressure pulse within the casing that will be detected and cause arming of perforating gun B but will not arm perforating gun C, which remains disabled or un-armed so that it cannot be fired simultaneously with or before the charges of perforating gun B is fired. Subsequent firing of perforating gun B will arm perforating gun C so that perforating gun C will then be capable of firing assuming its firing safety parameters have all been met.

[0028] The general firing parameters for safe conveyance, positioning and firing of perforating guns and other well service tools are set forth is U.S. Pat. No. 5,369,579 of Otis R. Anderson. Subsequent firing of perforating gun B will arm perforating gun C so that perforating gun C will then be capable of firing assuming all of its firing parameters have all been met.

[0029] With reference to FIGS. **2** and **3**, an electronic blast control system incorporating the features of this invention is illustrated generally at **24** and incorporates an elongate instrument body shown generally at **26** having an upper housing sub **28** within which is located a battery **30**. The upper housing sub **28** is provided with a threaded upper connection member **32** which is adapted for connection of the blast control instrument to a conventional wireline running tool to thus enable the instrument **24** to be run into a well bore and positioned at a predetermined depth within the well for sequential blasting or tool actuating operations. The upper housing sub **28** also includes an externally threaded downwardly extending connector projection **34** to enable its physical and electronic coupling with other electronic components of the blast control system or instrument **24**.

[0030] The housing structure of the instrument **24** also includes an intermediate pressure housing section **36** which is coupled and sealed in relation with the upper housing sub and which is also coupled and sealed in relation with the uppermost one of one or more detonator blast joints containing a plurality of spaced detonators **38**A, **38**B and **38**C which are selectively electrically initiated by means of electrical current from the storage battery **30** under circumstances where multiple safe parameters of the blast control have been met so that electrical initiation of the detonator is permitted. The detonators, upon selective sequential or serial initiation, will then achieve detonation of one or more shaped explosive perforating or gas generating charges that are contained within the blast joint or joints for achieving the explosive initiated downhole work that is desired.

[0031] The pressure containing housing **36** defines an internal chamber **40** having therein a plurality of electronic control modules which sense programmed well conditions such as fluid temperature and hydrostatic pressure, which sense the motion of the instrument as it traverses the well bore or well casing while being inserted into or removed from the well and which provides a predetermined timed sequence within which the downhole blasting operation is permitted to occur. These pressure, temperature and motion sensors and a clock timer provide electronic logic pulses which define safe and unsafe parameters for downhole blasting operations. These electronic logic signals are input to a central processing unit **42** having a microprocessor providing a firing signal output which controls battery current energization of the detonator circuit for electronic initiation of the detonator. The detonator will then initiate the explosive charge or charges which are typically first order explosive devices but which may comprise any other suitable explosive device for the work that is intended.

[0032] In preparation for downhole blasting activities, the blasting device is handled during transportation to the well site and is then handled by well personnel in preparation for its introduction into the well bore. After it is introduced into the well bore, typically by means of conventional wireline equipment, it must be run through the well bore to the designed depth for explosive detonation and must be secured relative to the well casing prior to detonation. During handling and running of the downhole blasting tool, it is critical that explosive detonation not occur.

[0033] It is also desirable that explosive detonation occur only when the blasting tool has accurately performed. For these reasons, according to the teachings of the present invention, the electronic blast control system of the present invention is provided with a plurality of sensors and a clock timer that each provide an output of logic signals reflecting sensed conditions. These logic output signals are conducted to the CPU **42** and are processed thereby. When predetermined logic output signals are received by the CPU, its signal processing will yield a CPU output signal causing battery current to be placed across the detonator circuit thereby initiating the detonator and inducing controlled blasting activity. If the output signals of the clock timer or any of the well condition sensors are not in accordance with predetermined programmed conditions that are necessary for blasting activity, CPU processing of the signals will yield a logic output signal that prevents detonator circuit energization by the battery section of the tool. The electronic blast control system includes a motion sensor circuit **44** which detects any movement of the tool as it is being handled at the surface and run into the well bore. The motion sensor also detects movement of the tool as it is being extracted from the well bore under conditions where, for any of a number of reasons, detonation will not have occurred. The motion sensor circuit includes a timing sequence which is initiated each time motion of the tool ceases within the well bore. A timing sequence of any suitable duration may be employed which is suitable to the user. Thus, if the tool becomes temporarily stuck within the well bore during running and thereby becomes motionless, since it is not located at its designed depth for detonation, the motion sensor circuit will not yield a logic signal permitting firing of the detonator until the timing sequence period has completed. Thus, should the tool become stuck within the well casing during running, the timing sequence will become reset. Accordingly, before the detonator can be fired, the timing sequence of the motion sensor must have run its course and remain stable for a period exceeding the duration of the timing sequence.

[0034] It is desirable that the downhole blasting system be capable of detonating only during a predetermined period of time. It is necessary that initiation of the detonator not occur until a predetermined time that is sufficiently far in advance so that the blasting tool can be properly positioned at its designed depth and proper orientation within the well casing. It is also desirable that there be a capability of pre-setting a timed period during which detonator initiation can occur and before which and after which initiation of the detonator cannot occur. Thus, if the detonators and their various associated apparatus has remained downhole for a period that is sufficiently long to exceed a predetermined time duration, for example, two hours, then it is desirable to safely prevent initiation of the detonator, thereby enabling the electronic blast control system together with the detonators and blast joints to be removed from the well. To accomplish this feature, a clock timer circuit **46** is provided within the pressure containing chamber **40** of the pressure containing housing **36**. The clock timer circuit **46** derives its electrical energy from the battery **30** and provides a logic output signal having a predetermined logic state when the clock timer circuit is within the predetermined firing period and an opposite logic state when the clock timer circuit is registering a time that is either before or after the predetermined firing period. The logic output signals of the clock timer circuit are transmitted to the CPU for processing so that the firing signal that is output by the CPU can occur only when the timing sequence is within the firing period that is set or programmed at the surface by operating personnel.

[0035] In the downhole environment the well casing will contain a level of drilling fluid or completion fluid which will develop hydrostatic pressure within the well casing that is directly responsive at which the depth at which the hydrostatic pressure is taken. Obviously, hydrostatic pressure at any predetermined depth within the well casing can be quite accurately identified. As an additional safety feature, the electronic blast control system of the present invention, shown by way of elevation in FIG. **2** and shown schematically in FIG. **3**, is provided with a pressure sensor circuit **48** which is energized by the battery **30** and which senses hydrostatic pressure to which the blast control system is subjected. The pressure sensor circuit **48** provides an electronic logic output reflecting the hydrostatic pressure to which the tool is subjected at any point in time. This logic output is conducted to the CPU which processes these signals along with other logic signals.

[0036] The circuit is capable of being pre-set or programmed to a predetermined hydrostatic pressure range such that when hydrostatic pressure is within the predetermined range, such that when hydrostatic pressure is within the predetermined range a firing signal can be output by the CPU. If the hydrostatic pressure being sensed is outside the predetermined range, then the logic signal being received by the CPU will be such that the CPU cannot provide a firing signal, but rather, will provide a “safe” signal preventing initiation of either of the detonators **38**A-**38**C by electrical energy from the battery **30**. Thus, well servicing personnel will set the predetermined firing pressure range of the pressure sensor for a rather narrow range of hydrostatic pressure that is calculated to be present at the well depth where firing of the blast joints or blasting system should occur. This provides assurance that the electronic blast control system and its downhole explosive system will be properly located at a designed depth within the well bore before a firing control sequence can be initiated by the CPU.

[0037] Thus, at a designed depth within a well bore the temperature of the well fluid, which will be directly representative of formation temperature, will have a known narrow range of temperature values. As a further safety feature, the electronic blast control system of this invention is provided with a temperature sensor circuit **50** having the capability of detecting the temperature of the well fluid being produced from each formation. This temperature sensor circuit has the capability of being preset with a narrow firing temperature range which will encompass calculated or measured temperature at the predetermined firing depth of the downhole explosive system. When the fluid temperature being sensed is within the predetermined firing range, a logic output signal of the temperature sensor will be conducted to the CPU for processing. As long as the temperature being sensed is within the firing range, the logic output signal received by the CPU will enable the CPU to output a firing signal. If the temperature being sensed by circuit **50** is outside of the firing temperature range, such as would occur if the electronic blast control system is not located at designed well depth, the CPU will output a “safe” signal, thereby preventing initiation of the detonator by the electrical energy of the battery **16**. In order for the CPU to output a “firing” signal, the respective logic signals output by the motion sensor circuit, the clock timer circuit, the pressure sensor and the temperature sensor must reflect positioning of the downhole blasting system at designed well depth and within a predetermined timing sequence in order for the downhole blasting system to fire. If the blasting system is not fired, or for some reason fails to fire, the tool is rendered safe for extraction from the well simply by permitting expiration of the predetermined sequence that is programmed into the clock timer. Then, as the blast control system and its associated blasting tool is moved toward the surface during extraction procedures, the other safety circuits will come into play.

[0038] The motion sensor circuit will detect upward motion of the tool and will change its logic output signal to the "safe" mode, thereby preventing output of a firing signal by the CPU. Likewise, as the tool is moved uphole, the pressure sensor circuit and the temperature sensor circuit will detect hydrostatic pressure and well fluid temperature that is outside of the prescribed range for the firing sequence. These circuits will then also change their respective logic output signals to the "safe" mode, thereby preventing the CPU from having a "firing" mode output signal that permits initiation of any of the detonators **38**A-**38**C by the electrical energy of the storage battery **30**.

[0039] When two or more explosive energy devices are properly positioned within a wellbore or well casing it is desirable to prevent them from simultaneous firing; but rather to control their firing according to a sequence. As shown in FIG. **3** an arming circuit is shown at **54** which may be integrated with the CPU **42** or it may be provided as a separate circuit. The arming circuit will permit only one of two or more detonators to be fired at any given time. Firing of the lowermost detonator **38**C will cause an electronic arming signal or an explosive generated pressure pulse to actuate the arming circuit **54** and generate an arming logic signal to the next detonator **38**B. Only then will the next detonator be permitted to fire. Its firing will then stimulate the generation of an arming logic signal that arms the detonator circuit **38**A and permits its firing. Thus with the minimum cost of running multiple well service tools into the well casing by means of a single wire line run, multiple well service operations can be safely and efficiently carried out.

[0040] Referring to FIG. **4**, the storage battery **30** is incorporated within or is electrically connected with a power supply circuit **56** that boosts the low voltage, 15 volts for example, to a sufficiently high voltage, 144 volts for example, for firing energization of an explosive charge detonator. Detonator circuits **58**, **60** and **62** are connected with the power supply circuit and have diodes that are alternatively arranged to provide positive or negative voltage as an additional level of safety for sequential firing of the detonators. Detonator circuit **58** has a diode **64** having its gate arranged to permit the flow of positive 144 volt energy for firing energization of the detonator **38**C. The detonator **38**B will not fire by positive voltage but will fire by negative voltage. The firing circuit **60** includes a diode **66** having its gate arranged to permit passage of negative voltage and block positive voltage. Thus when positive voltage is transmitted via circuit conductor **58** it will fire detonator **38**C but will be blocked by diode **66** from also actuating the detonator **38**B. As mentioned above, and as a principal safety factor, the positive electrical pulse of the power supply will only fire the lowermost detonator **38**C since the upper and intermediate detonators will be protected from firing by the exclusion feature of the arming circuit **54**. The diode **68** of detonator circuit **62** is arranged to pass only positive voltage for firing of the detonator circuit **38**A.

[0041] As the electronic blast control is being run downhole, it is positioned for firing and is fired, it is desirable to identify various downhole conditions of pressure and temperature for determination of formation conditions. It is also desirable to identify pressure and temperature conditions immediately after firing as further evidence of formation conditions. These features are effectively provided for by the electronic blast control system of the present invention which incorporates a solid-state, non-volatile memory circuit **52**, as shown in FIGS. **2** and **3**, which continuously receives the output logic signals of the pressure and temperature circuits and also receives the output signals of the clock timer circuit **46** in order that the pressure and temperature signals may be correlated with time. The data format of the memory circuit **52** is such that multiple thousands of sets of Delta time, temperature, and pressure are stored in the solid-state, non-volatile memory. After the electronic blast control system has been removed from the well, the memory circuit **52** is selectively coupled with the input of a computer having a program and a memory adapted for receiving and processing the multiple data sets of the memory circuit. Thus, the computer can provide processed downhole data from the well, reflecting well conditions before and after blasting as well as well conditions. This information may be plotted graphically or rendered by the computer in any suitable form that is desired for analysis.

[0042] With reference to FIG. **5** a timing sequence is shown in schematic form, based on a ten minute timing interval. However, it is to be borne in mind that the particular timing sequence that is shown is not to be taken as limiting the spirit and scope of the present invention, since the timing sequence can be variously arranged to suit the user. Below the timing sequence is shown the motion condition of the blast control system of the present invention in relation to the timing sequence. In minute 5 of the 10 minute interval of the timing sequence a programmed activity can take place assuming the well service tool and its blast control system is not in motion, which is the case that is shown in the schematic illustration. No blast control firing can occur during timing segments **1**, **3** and **7** since the motion of the instrument within the wellbore or well casing is received by the CPU and processed as a logic signal that renders the instrument to its "safe mode", preventing firing of the well service tool.

[0043] In view of the foregoing it is evident that the present invention is one well adapted to attain all of the objects and features hereinabove set forth, together with other objects and features which are inherent in the apparatus disclosed herein.

[0044] As will be readily apparent to those skilled in the art, the present invention may easily be produced in other specific forms without departing from its spirit or essential characteristics. The present embodiment is, therefore, to be considered as merely illustrative and not restrictive, the scope of the invention being indicated by the claims rather than the foregoing description, and all changes which come within the meaning and range of equivalence of the claims are therefore intended to be embraced therein.

I claim:

1. A method for sequentially controlling the performance of work in an environment with a plurality of service mechanisms, comprising:

selectively positioning a plurality of explosive actuated service mechanisms in work performing arrangement and in serial fashion, each of said service mechanisms having an electronically initiated explosive charge;

securing said electronically initiated explosive charge of each of said service mechanisms against electronic initiation until predetermined individual safety parameters of each of said electronic charge initiation circuits have been met;

preparing an electronic charge initiation circuit connected with each of said electronically initiated explosive charges for passing a predetermined electronic voltage and for blocking a different electronic voltage;

selectively applying a predetermined electronic voltage from a voltage source to a first of said plurality of explosive actuated service mechanisms and initiating the explosive charge thereof and serially performing work ; and

selectively applying a different electronic voltage from the voltage source to a second of said plurality of explosive actuated service mechanisms and initiating the explosive charge thereof and serially performing additional work.

2. The method of claim **1**, comprising:

said predetermined electronic voltage having a designated polarity energizing the explosive charge of said first of said plurality of explosive actuated service mechanisms and said different electronic voltage having the opposite polarity energizing the explosive charge of the second of said plurality of explosive actuated service mechanisms.

3. The method of claim **1**, comprising:

one of said electronic charge initiation circuits converting power supply voltage to a positive voltage representing said predetermined electronic voltage and another of said electronic charge initiation circuits converting said power supply voltage to a negative voltage.

4. The method of claim **3**, comprising:

said converting power supply voltage being applying battery voltage to selectively arranged diodes and yielding selective positive and negative voltages; and

stepping up battery supply voltage to explosive charge initiating voltage.

5. The method of claim **1**, comprising:

running a service tool into a well having a well casing, the service tool having a plurality of service sections being sufficiently spaced that explosive energization of said first of said plurality of explosive actuated service mechanisms will not render others of said plurality of explosive actuated service mechanisms inoperable;

said selectively applying a predetermined electronic voltage being controlling a battery type power supply located on board said service tool and establishing gate circuit controlled positive and negative voltage outputs; and

arming successive explosive actuated service mechanisms by detection of energy pulses caused by energization of preceding explosive actuated service mechanisms.

6. The method of claim **5**, comprising:

said well service tool being a casing perforating assembly having a plurality of spaced serially arranged casing perforating guns each having a plurality of electronically initiated explosive shaped charges;

establishing electronic initiation of a first of said plurality of spaced serially arranged casing perforating guns from an on board battery supply by a voltage having a selected polarity;

a second and subsequent casing perforating guns being disarmed during said running and positioning and being armed by an explosive generated pulse caused by energization of the explosive charges of said first of said plurality of spaced serially arranged casing perforating guns; and

energizing said second and subsequent casing perforation guns serially according to a programmed initiation sequence and subject to programmed safety parameters.

7. A control system for controlling the sequential or serial performance of work in an environment, comprising:

a service tool having a plurality of spaced and serially arranged electronically initiated service mechanisms each having an explosive detonator being initiated by an electronic voltage of selected polarity;

an electronic controller system having a central processing unit (CPU) and a power supply electronically connected with said service tool and having selective positive and negative voltage outputs, said CPU being programmable and establishing at least one safety parameter that must be met to arm said explosive detonators for electronic initiation;

a first of said spaced and serially arranged electronically initiated service mechanisms being electronically initiated by said CPU and initiating said explosive detonator thereof with said electronic voltage of selected polarity, the detonation thereof producing an energy pulse; and

a second of said spaced and serially arranged electronically initiated service mechanisms having an arming circuit being normally unarmed and becoming armed upon sensing of the energy pulse, said second of said spaced and serially arranged electronically initiated service mechanisms being electronically initiated by said CPU and by an electronic voltage having opposite polarity as compared with said selected polarity.

8. The control system of claim **7**, comprising:

said environment being a well having a casing;

said plurality of spaced and serially arranged electronically initiated service mechanisms each being a casing perforation gun having an electronically energized explosive detonator connected for energization by said CPU; and

said CPU having a solid state non-volatile electronic memory adapted for input of safety parameters including time, temperature, pressure and movement and providing a firing signal when each of the safety parameters have been met, said firing signal initiating only the detonator of said first casing perforation gun, said second casing perforation gun having an unarmed state and being armed by a pulse signal transmitted to said CPU in response to detection of the energy pulse of detonation of the first perforating gun, said CPU conducting a firing signal having a polarity opposite said selected polarity to said second casing perforation gun upon energy pulse responsive arming of the detonator of said second perforation gun.

9. The control system of claim **7**, comprising:

an energy pulse sensor being coupled for energy pulse signal transmission to said CPU upon firing the detonator of a first of said perforation guns; and

said second of said perforation guns being in a disarmed state when positioned within the well and being armed by said CPU responsive to transmission of an energy pulse signal to said CPU to permit firing of the detonator thereof by a CPU controlled firing signal.

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