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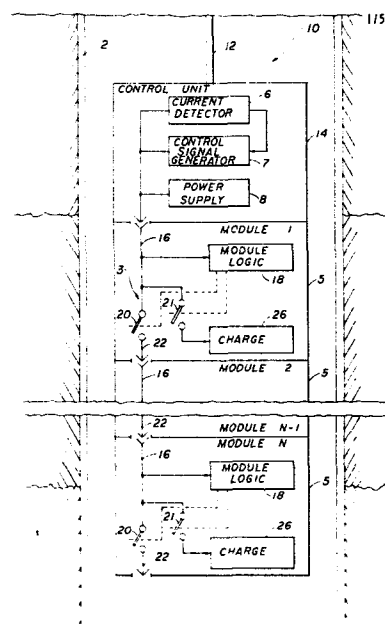
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(54) **A single-wire selective perforation system having firing safeguards.**

(57) A method and system for selecting and arming each of a plurality of firing modules in a single-line selective perforating system is disclosed. A single firing line connects each firing module one at a time in a sequence to a control unit to receive power and control signals therefrom. Each module generates internally a module active time interval in response to being connected to the firing line power. Each time interval has a first portion during which the module generates an identification pulse to the control unit to uniquely identify that a particular module has been connected to the firing line, and a second portion during which the module is enabled to receive a selection pulse from the control unit to terminate further sequencing of the modules to locate the module to be selected. The next module to receive power from the control unit is connected to the firing line by a pass-through switch in the last connected module at the end of its active time interval if that module was not selected.



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A SINGLE-WIRE SELECTIVE PERFORATION
SYSTEM HAVING FIRING SAFEGUARDS

BACKGROUND OF THE INVENTION

This invention relates to perforating guns used in well completion operations. More particularly, the present invention relates to a single-wire selective gun perforating system capable of selecting and firing in an arbitrary order each gun in a plurality of guns connected in a firing string.

Typical prior-art perforating guns generally used in well completion operations consist of a plurality of guns connected vertically to form an assembly or firing string suitable for lowering into a well borehole. Each gun will contain one or more shaped charges. Each charge will have a detonator or blasting cap connectable to a firing wire for receiving an electrical firing pulse to detonate the charges.

It is often desirable in well completion operations to have each gun selectable for firing rather than having all guns firing at the same time. Firing all guns at the same time produces perforation spacing determined by the spacing of the guns in the string, usually in a closely-spaced arrangement. On the other hand, individual detonation of the charges permits perforations to be made at various selected depths, and in various selected (often widely separated) zones. As each charge is detonated, the string can be repositioned to the next level where another perforation is desired, and another gun fired. This process can continue until the proper perforation spacing is obtained with the desired number of shots. A further benefit is obtained from the single detonation of the guns -- verification that each gun fired and that the proper number of perforations was obtained.

However, the selection and firing of a single gun in the string may involve failures which would prevent the proper firing of the modules. A failure could occur in the gun to be selected that would prevent it from firing; a failure could occur causing the firing of a wrong gun which will be eventually detected; or a failure could occur which caused the undetected firing of a wrong gun. Any one of these failures, especially in many of the prior art devices, would defeat the purposes of having selective firing of the guns in the perforation operations.

Many selective firing systems and methods have been used in the prior art to select a gun for firing from among the plurality of guns in the string. U.S. Patent 4,051,907 discloses one such system comprising a surface control unit for controlling the selection and firing of the guns in a firing string comprised of a subsurface master unit operatively connected to a plurality of identical slave sub units or firing modules that may be armed and fired in an arbitrary order under control of the master unit and an operator.

Sequencing through the firing modules for selection of a module to be fired is under control of the surface located control unit. The selection process begins at the uppermost firing module closest to the master unit. Each firing module contains a pulse counter which receives pulses from the surface via the master slave unit when that module has been connected to the firing line power. A predetermined number of pulses (8 pulses) sequences the counter through nine counts. At selected counts, certain operations are effected in the module. For example, at count 4 a current pulse is placed on the firing line, at count 5 a switch is closed to charge a firing capacitor with the voltage currently on the firing line, at count 6 a firing pulse whose amplitude is equal to the current voltage on the firing line is applied to a blocking zener diode which is connected to a firing switch (the firing switch is not closed because the voltage on the firing line is not greater than the break over voltage of the zener diode), and at count 9 a pass-through switch is closed to pass the firing line power on down to the next lower module in the string.

The above described process is then repeated for the next module to be connected to the firing line power. As long as eight pulses are issued without a change in the firing line power, the sequencing through the firing modules will continue, one at a time. When the firing module to be selected and fired is reached, only six pulses will be issued by the master unit under control of the operator. These six pulses take the pulse counter in the firing module to be selected to a count of five which closes the switch which connects the firing line to the firing capacitor. At this point, the operator at the surface activates the arm switch which raises the firing line voltage, and thus the firing capacitor, to a value

sufficient to detonate the charge when the capacitor is discharged into the blasting cap. Six pulses arm the firing module with one more pulse causing a closing of the firing switch to occur since the firing line voltage is now greater than the blocking zener diode voltage to permit the firing switch to be closed. Closure of the firing switch connects the firing capacitor across the blasting cap circuit.

These prior-art selective perforating systems, such as that disclosed in 4,051,907, suffer from several disadvantages. One disadvantage is the need for elaborate surface and subsurface circuitry with continuous supervision and interaction required between the surface and subsurface circuitry during the selection process to effect the selection and arming of the firing modules. Another disadvantage is that sequencing through the firing modules is solely under control of the surface equipment. Another disadvantage is the lack of any safeguards for detecting faults in the firing string which will prohibit the proper firing of a single selected module.

Accordingly, it would be advantageous to provide a single-wire selective perforating system which provides for the automatic sequencing through the firing modules in a sequence, one at a time, under control of the modules themselves until a module to be selected is receiving power from the firing line. At that time the module can be selected and armed for firing. It would also be advantageous to provide a single-wire selective perforating system which includes safeguards for determining if a single module has been connected in the sequence to the firing line and is operating within predicted power limits thereby insuring that one module is being selected for firing and that only that module will be fired by the firing pulse.

SUMMARY OF THE INVENTION

One aspect of the present invention is directed to in a single-line selective perforating system having a single firing line for electrically connecting a firing control unit to each of a plurality of shot modules, one at a time in a predetermined sequence, where each module is adapted for connecting the connected control unit to a next module, a method of selecting a module for firing characterized by the step of connecting each module one at a time in the predetermined sequence to the firing line under control of module active time intervals internally generated in the modules, where each module generates its active time interval in response to being connected to the firing line with the next module in the sequence automatically connected to the firing line at the end of the active time for the last connected module if that module was not selected for firing during its active time interval.

Another aspect of the present invention is directed to a single-wire selective perforating system for selectively detonating the charges in a plurality of firing modules, one at a time, comprising: (a) a control unit operatively connected to the modules by a single firing line which carries both power and control signals between said control unit and the modules; and (b) a plurality of selectable firing modules vertically connected one to another for form an elongated assembly suitable for lowering into a well borehole, the assembly including said control unit, and characterized in that each module, (i) containing at least one charge and where each module is automatically connected one at a time to the firing line in a predetermined sequence to receive power therefrom, and (ii) in response to receipt of power on the firing line, internally generates a module active time interval during which the module and its charge may be selected for firing by said control unit, each module not selected for firing during its active time interval automatically connecting the firing line to the next module in the sequence.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the present invention, reference should be had to the following detailed description taken in connection with the accompanying drawings in which:

Figure 1 is an illustration of the firing string for the present invention suspended in a well borehole;

Figure 2 is a functional block diagram of an embodiment of the firing module illustrated in Figure 1;

Figure 3 is a timing diagram illustrating operations of the present invention for selecting, arming and firing a selected module of the type shown in Figure 2;

Figure 4 is a functional block diagram of another embodiment of the firing module illustrated in Figure 1; and

Figure 5 is a timing diagram illustrating operations of the present invention for selecting, arming and firing a selected module of the type shown in Figure 4.

Similar reference numerals refer to similar parts throughout the several views of the drawings.

BRIEF DESCRIPTION OF THE
PREFERRED EMBODIMENT OF THE INVENTION

Referring now to the figures and first to Figure 1, a firing string 10 according to the present invention is shown suspended by a cable 12 in well borehole 1 having a well casing 2. The firing string 10 includes a control unit 14 connected to the cable 12 at the uppermost end. Control unit 14 functions to generate the control signals and firing line 3 power needed by the firing modules to select and arm their charges for firing. Connected one to another below the control unit 14 is a plurality of identical firing modules 5 to form an elongated assembly suitable for lowering into the well borehole 1.

Control unit 14 contains a current detection means 6 for detecting the amount of current in the firing line 3; a control signal generator 7 for generating control signals to the firing modules to select and arm for firing a module to be selected and to generate a firing pulse to detonate the module selected and armed for firing; and, a controllable power supply 8 for generating the voltage and current needed to power the firing modules.

Each of the firing modules 5 contains at least one shaped charged 26 (See Figure 2) with an associated detonator 24 to form a shot or gun for blasting a hole through the well casing 2 into the subsurface formations. Also included in each module is a module logic circuit 18 which functions in cooperation with the control unit 14 and the signals on

the firing line 3 generally indicated in Figure 1 by the segmented signal leads 16, 22 contained in each of the modules 5. As will be discussed below, the firing line from the control unit 14 to the various modules 5 consists
5 of a series of segmented leads which are electrically connected together in sequence to form a single firing line 3 as the various modules are connected one at a time in a prescribed sequence to the control unit 14. Each module 5, when physically connected to another module in
10 the string 10 makes electrical contact with a portion of the firing line of the module to which it is connected. That is, the portion 16 of the firing line of the module just connected makes electrical contact with portion 22 of the next higher module to which it is connected.

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Still referring to Figure 1, each firing module 5 contains a controllable switch means illustrated as switches 20 and 21, which responds to the module logic circuit 18 to either pass the input portion 16 of the
20 firing line 3 coming into the firing module onto the output portion 22 of the firing line 3 which passes the firing line power on down to the next module in the string (switch 20), or connects the input portion 16 of the firing line 3 to the detonator 24 of the shaped charge 26
25 (switch 21). If switch 21 is closed in a module, that module would be the module selected for firing and the module logic circuit 18 of that selected module would inhibit further sequencing of lower modules in the string 10 by inhibiting switch 20 from being closed to pass the
30 firing line power on through to the next lower module. In those modules sequenced but not selected during their respective active time intervals, the pass-thru switch 20 could also include switching to ground their detonator so that accidental firing cannot occur.

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Sequencing of the selectable firing modules begins with the uppermost module connected to the control unit 14. The uppermost module receives power from the control unit 14 when power is first applied to the firing line 3. Thereafter, as each firing module completes its selection process and is not selected for firing, the next lower module in the string is then connected to the firing line. This process continues until the lowermost module has executed its selection sequence.

The selection sequence for each firing module 5 is best described with reference to Figure 2 which illustrates the functional block diagram for a typical firing module. Referring now to Figure 2, the input portion 16 of the firing line 3 is connected to a constant current power supply 29 for regulating the voltage on the firing line 3 to produce the supply voltage for the circuits of the module. The firing line is also connected to a firing line pulse detector 37. The output from firing line pulse detector 37 is connected to a flip-flop 41. Together, pulse detector 37 and flip-flop 41 comprise a stop pulse detector 34 for generating a stop pulse to terminate the module active time interval if the module is to be selected and armed for firing. The firing line pulse detector 37 responds to voltage pulses on the firing line to detect when the control unit 14 has issued selection and arming pulses on the firing line 3.

Also included in each module is a counter circuit means 32 which responds to an internal oscillator clock 28 to produce internally to the module a module active time interval during which the selection of the module for firing is possible. The oscillator clock 28, in conjunction with the number of bits in the binary counter 35 included in the counter means 32, determines the length of

the module active time interval. A power reset pulse generator 30 is also included in each module 5 for generating a reset pulse upon the initial receipt of power on the firing line 16. The power reset pulse initiates the start of the active time interval by resetting counter 35.

The power reset pulse has an additional function of generating a current increase pulse on the firing line 3 back to the control unit 14 to indicate that a next module has been connected to the firing line 3. This current pulse is the identification pulse for the module, and must meet certain requirements. First, the magnitude of the increase in the firing line 3 current must be within a predetermined range to indicate that the just connected module is operating in acceptable limits and that only one module is responding to the firing line power. Second, the occurrence of the identification pulse must be within a predetermined window measured from the last identification pulse on the firing line.

The control means 14 includes (not shown) a means for detecting the amount of current on the firing line. There are several reasons for monitoring this current. First, by counting the number of identification pulses generated on the firing line, the control means 14 can determine which of the modules has just been connected to the firing line. In this manner, the module to be selected can be detected as the modules automatically sequence through their active times. The control means 14 also includes a means for generating both the selection and arming signals as well as the firing pulse which will detonate the module which has been selected and armed for firing.

Still referring to Figure 2, the stop pulse detector 34 is shown comprised of a firing line pulse detector 37 which responds to signals on the input portion 16 of the firing line 3, and a flip-flop 41 that, in turn, responds to the output of the firing line pulse detector 37 and the binary counter 35, to generate two control signals. First, a STOP CLOCK signal is outputted by flip-flop 41 on line 50 to one input of an AND gate 33. Also inputted to AND gate 33 is the output from oscillator clock 28. AND gate 33, when enabled, outputs the clocking signal to counter 35. The signal STOP CLOCK functions as a disable signal to inhibit further clocking of the counter 35 when the selection pulse is received on the firing line 3.

When the signal STOP CLOCK goes to a logic zero, AND gate 33 will be inhibited from supplying any further clock signals to the counter 35. At the same time that STOP CLOCK goes to a logic zero, the signal ARM CONTROL, also outputted by flip-flop 41, goes to a logic one. ARM CONTROL appears on signal lead 39 to the firing switch 21. The signal ARM CONTROL closes the firing switch 21 to connect the cathode of zener diode 43 to the detonator 24 associated with the shaped charge 26 of the module. The anode portion of the zener diode 43 is connected to the input portion 16 of the firing line 3. For this preferred embodiment of the invention, the selection pulse on firing line 3 also acts to arm the module for firing.

The improved single-wire selective perforating system referred to above, has separated the selection and arming functions to improve the feedback safeguards to avoid failures during firing that result in faulty operations. Specifically, a single pulse is used to select a module and a sequence of three arming pulses is used to arm the module in a predetermined sequence. The first arming

pulse causes the module to be armed to produce a current increase in the firing line 3 current. This current increase must be within a predetermined range. A second arming pulse will remove this current increase. If the
5 value of the current increase is acceptable and the increase was cleared by the second arming pulse, then a third pulse is issued to arm the module for firing. The firing pulse to detonate the charge can then be issued with the assurance that one and only one module will be
10 fired.

Still referring to Figure 2, the flip-flop 41 of the stop pulse detector 34 functions as a set-reset type flip-flop where the set signal comes from the firing line pulse detector 37 and the reset signal comes from the
15 counter 35. The reset signal to flip-flop 41 is labeled ENABLE and is at a logic one state when the Q11 output from the 12-bit binary counter 35 is true. When the reset input to flip-flop 41 is at a logic one, the flip-flop can be "set" to a logic one by a pulse on the set input.
20 Thus, a pulse detected by the firing line pulse detector 37 will cause flip-flop 41 to change states (logic zero to logic one) only if the signal ENABLE on signal lead 46 from counter 35 is true. During the first portion of the active time interval for the module, the signal ENABLE
25 will not be at a logic one. After a certain number of clock pulses have been counted, ENABLE goes true making the start of the second portion of the module active time interval. It is during this second portion that the
30 module may be selected and armed.

Also inputted to the AND gate 33 is another output from the binary counter 35 (Q12) which represents the most significant bit from the 12-bit counter. The signal on
35 the Q12 output, PASS-THROUGH, also controls the pass-through switch 20 which functions to connect the input

portion 16 of the firing line 3 to the output portion 22. Additionally, the signal PASS-THROUGH disables clock signals from the oscillator clock 28 from reaching the counter 35. As previously discussed, the flip-flop 41
5 enables the AND gate 33 to pass clock pulses from oscillator 28 to the counter 35 irrespective of whether any pulses are detected by the firing line pulse detector 37 during the first portion of the active interval.

10 The lapsing of the first portion of the time interval is indicated when the signal ENABLE on signal lead 46 goes to a logic one thereby permitting any subsequent pulses detected by the firing line pulse detector 37 to set the flip-flop 41 and disable AND gate 33. In the event that
15 no firing line pulses are detected by detector 37 during the second portion of the active time interval, then the Q12 output of counter 35 will eventually go true and produce the signal PASS-THROUGH to inhibit further clocking of the counter 35. Simultaneously, the pass-through
20 switch 20 is closed to pass the firing line power on to the next module down the sequence. Closure of the pass-through switch 20 represents the end of the selection process for the module with the module thereafter connected to the firing line power. Further clocking of
25 the counter 25 is inhibited until the module is reset by removal of power on the firing line 3.

The timing relationships between the signals of the control unit 14 and the plurality of firing modules during the sequencing of the modules is illustrated in
30 Figure 3. Referring now to Figure 3, the voltage and current on the firing line are illustrated for a typical selection sequence involving three firing modules with the third module representing the module to be selected.
35 With application of power in the form of voltage and current on the firing line, module No. 1 will begin to

internally generate its module active time interval. The active time interval for each module is illustrated in Figure 3 as composed of two portions, a first and second portions T1 and T2, respectively. The first portion T1
5 represents the time interval from the initial receipt of power in the module to the time when Q11 of binary counter 35 goes true. The second portion of the time interval T2 represents the remaining portion of the active time interval and represents the time that Q11 from counter 35
10 is true. In other words, the end of the second portion T2 of each module time interval is indicated when the Q12 output of the binary counter 35 goes true and Q11 goes false (a true state is represented by a logic one and a false state represented by a logic zero).

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Upon receipt of power by the module No. 1, an identification pulse is generated on the firing line 3. The pulse is shown as a current increase in the firing line current. The increase indicates to the control unit 14
20 that a module has been connected to the firing line. If the amplitude of the current increase on the firing line for the identification pulse does not fall within a predetermined range, the control unit 14 will cease sequencing of the modules because a faulty operation, such as more
25 than one module 5 responding to the application of power on the firing line 3 or that the module just connected is not operating within predetermined limit, is indicated. As the signal for the firing line current shown in Figure 3 indicates, there is an increase in the firing line current
30 each time that another module is connected to the firing line apart from the superimposed current increase pulse for the identification pulse. These increases in firing line current result because each module remains connected to the firing line current at the end of its module active
35 time interval and continues to draw current until reset by removal of the firing line power.

For the example illustrated in Figure 3, at the end of the module active time interval for module 1, its pass-thru switch 20 is closed to connect module 2 to the firing line power. As shown in Figure 3, module 2 and
5 module 1 are now connected to the firing line resulting in a net increase in the amount of current on the firing line. This is generally illustrated as a step function increase. Superimposed on this step increase is the identification pulse for module No. 2.

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In addition to the identification pulse amplitude falling within a predetermined range, the control unit 14 monitors the time interval as measured from the receipt of the last identification pulse to receipt of the next
15 identification pulse. Unless each identification pulse falls within a predetermined time window measured from the last pulse on the firing line 3, the control unit 14 will terminate further sequencing of the firing modules because a faulty situation is indicated.

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An additional function of the identification pulses to the control unit 14 is to function as a clocking pulse to enable the control unit 14 to count which of the modules has just been connected to the firing line 3 power. Thus,
25 when the identification pulse for module 3 is received and the identification pulse conditions are met, control unit 14 will know that the module to be selected, module 3, has just been connected to the firing line 3.

30

As previously discussed, any pulses occurring on the firing line during the first portion of the time interval will have no effect on the selection and arming of a module. Only during the second portion of the active time interval T_2 will the flip-flop 41 be enabled to receive
35 setting pulses detected by the firing line pulse detector

37 to select and arm the module. In the example illustrated in Figure 3, since module No. 3 is the module to be selected, the control unit 14 will generate a selection and arming pulse on the firing line indicated as a voltage pulse on the firing line voltage during T2 for module No. 3. When the firing line pulse detector 37 detects the voltage pulse on the firing line voltage during the second portion of the module active time interval, flip-flop 41 will be triggered to terminate further counting of the counter 35 and to generate ARM CONTROL to the firing switch 21. With ARM CONTROL true, firing switch 21 will be closed connecting the detonator 24 in module No. 3 to the firing line through its zener diode 43.

Since further clocking of counter 35 has been terminated by receipt of the selection pulse and the setting of flip-flop 41, the module will no longer be in an active time interval generation operation, but will have to be in a selected state. Further selection of lower modules is terminated and detonation of module No. 3 can occur at any time control unit 14 wishes to apply a firing pulse on the firing line. Should detonation of the selected and armed module not be desired, the selection sequencing process can be repeated by resetting all of the modules back to the initial state by removing the firing line voltage and current momentarily. When the power is removed, all the pass-through switches 20 and the firing switch 21 in module 3 will be switched to their open position so that only the first module connected to the control unit 14 will receive power on the firing line 3 once power is again returned.

Summarizing the present invention, a single-wire selective perforating gun system is disclosed in which a plurality of identical firing modules are connected, one to another, to form an elongated assembly suitable for
5 lowering into a well borehole. Included in the assembly is a control unit for generating power and firing line signals to each of the firing modules as each module is connected one at a time in a sequence to the control unit.

10 Each of the firing modules generates internally an active time interval during which the module can be selected and armed for firing by the control unit. The active time interval begins when power is applied to the module by connection of the module to the firing line.
15 Each firing interval has a first and a second portion. During the first portion, the firing module generates an identification pulse to the control unit to indicate that a next module has been connected to the firing line. In this way, the control unit counts the modules as they are
20 connected to the firing line to determine when the module to be selected is generating an active time interval. During the second portion of the module active time interval, the control unit may select a module for firing by issuing a selection control pulse onto the firing line.
25 Pulses on the firing line during the first portion of the active time interval are disregarded by the module since a module may only be selected and armed during the second portion of the time interval.

30 As a safeguard against attempting to fire a module when conditions of the modules do not permit, each module generates an identification pulse on the firing line which the control unit monitors to determine if the module is

operating within acceptable power limits and that the sequencing through the modules has occurred within prescribed time limits. Only when conditions are proper will the control unit select and arm for firing the module to be selected.

The selection process for each firing module 5 is best described with reference to Figure 2 which illustrates the functional block diagram for a typical firing module 5. Referring now to Figure 2, the input portion 16 of the firing line 3 is shown connected to a regulated power supply 29 which produces the supply voltage for the circuits of the module. For purposes of the following discussion, it is assumed that the firing module shown in Figure 2 has just been connected to the firing line power by the closure of switch 20 in the module immediately above.

The firing line is also shown connected to a control pulse detector 34. The control pulse detector 34 consists of a R-C network to shift the DC level of the control pulse which is applied directly into the clock input of a 4-bit shift register 38. The shift register's clock input stage acts as a comparator to detect the control pulses.

The control pulse detector 34 generates on the Q1 output of shift register 38 the signal STOP CLOCK in response to a selection control signal on the firing line during the active time interval. The selection control signal, if received at the proper time during the active

time interval, selects the module for firing by terminating the module's active time interval which prohibits switch 20 from thereafter closing and passing power to the modules below the selected module. In addition to
5 detecting a selection control signal on the firing line, the control pulse detector 34 detects the sequence of arming control signals from the control unit 14. This sequence of arming control signals is used as a safeguard
10 detection method for determining if one and only one firing module 5 is responding to the arming sequence.

Still referring to Figure 2, the last three stages of the 4-bit register 38 comprise an arming circuit which responds to the sequence of arming control signals
15 detected by the control pulse detector 34 to generate a feedback current pulse to the control unit 14. This feedback current pulse on the firing line 3 functions to indicate to the current detection means 6 in the control unit 14 that one and only one firing module is responding
20 to the sequence of arming control signals. As will be discussed below, this feedback current pulse acts as a safeguard detection method for potential problems which would result in the improper firing of the perforation
25 guns.

As mentioned previously, the arming sequence feedback current pulse on the firing line 3 has a predetermined amplitude of current increase over the firing line steady
30 state current to indicate that only a single firing module is responding. The 4-bit shift register 38 operates to produce this predetermined current pulse in the firing line as follows: As long as the signal on line 46 into shift register 38 (the data (D) input) is at a logic 0,

any detected control signals or pulses on the firing line will sequentially shift logic 0s into the various stages of the shift register 38. Logic 0s in the stages of the shift register 38 represents the reset condition. Thus,
5 any pulses detected by pulse detector 34 when the D input to shift register 38 is at a logic 0 will result in no change in the logic state of the shift register, and thus no action by the arming circuit.

10 When the data input to shift register 38 is at a logic 1, the first control signal detected by the stop pulse detector 34 on the firing line will shift a logic 1 into the first stage of the register. As previously discussed, the output of the first stage, Q1, is the signal
15 STOP CLOCK which is applied to signal line 50. The function of STOP CLOCK is to inhibit an oscillator clock 28 which is the internal time base for the logic circuits 18 from generating further clocking signals. The absence of further clocking pulses terminates the generation of
20 the module's active time interval and further sequencing of any lower modules. This first received control signal represents the selection control signal for selecting a module for firing. In other words, if STOP CLOCK goes to a logic 1, this module will be selected for firing. The
25 conditions under which the D input shift register 38 is at a logic 1 are discussed in more detail below.

Any further control signals detected by the stop pulse detector 34 when the D input is at a logic 1 will
30 cause a corresponding logic 1 to be shifted into each of the stages of the shift register 38, with the logic 1 shifted for each control signal detected. Connected between the output of the second stage, Q2, and the third stage, Q3, of the shift register 38 is a resistor R2.

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In accordance with the present invention, if the module is selected for firing by receipt of a selection control signal at the proper time, a series of arming pulses will then be generated by the control unit 14 to the arming circuit of the selected module 5 to generate the arming status feedback current pulse indicating that a single module is responding. This sequence of arming control signals consists of three pulses on the firing line. The first pulse causes the Q2 output of shift register 38 to go to a logic 1. At this time, the Q3 output of the shift register 38 is at a logic 0 thereby causing the 4-bit register 38 to supply current through R2 in the direction Q2 to Q3. This results in an increase in the amount of current drain on the power supplied by the firing line in an amount determined by the magnitude of R2. If a single firing module is responding, a predetermined current increase results.

With receipt of the second arming pulse, a logic 1 will also be shifted into the third stage of the shift register 38 resulting in both sides of resistor R2 being at a logic 1. This logic condition removes the current increase in the firing line current back to the current level for the reset condition of the arming circuit 38. Thus, if the amplitude of the current pulse increase in the firing line current as a result of the first and second arming pulses was within acceptable limits, the control unit 14 may then proceed to arm the module for firing.

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Arming of the module for firing is accomplished by issuing a third arming control signal on the firing line 3. This results in the fourth stage, Q4, of shift register 38 becoming a logic 1. The Q4 output of shift register 38

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is applied to signal line 39 as the signal ARM CONTROL. The signal ARM CONTROL is supplied to the controllable arming switch 21. For the present invention arming switch 21 and pass-through switch 20 are each solid state switches manufactured by International Rectifier as its model IRSC 232. Closure of switch 21 connects the detonator 24 for the shaped charge 26 to the input portion 16 of the firing line 3 thereby arming the module for firing.

As previously discussed, selection and arming of the module for firing occurs when a control signal is detected by the stop pulse detector 34 when the data input, D, to the 4-bit shift register 38 is at a logic 1. The data input to the shift register 38 is at a logic 1 during a portion of the modules active time interval and is generated as follows: A clock oscillator circuit 28 is provided as the module time base for generating clock pulses that will be counted by a 14-bit binary counter 34 to generate the active time interval for the module. The active time interval for each module is divided into two equal portions, T1 and T2 (see Figure 3). During the first portion T1, the module will perform an identification process whereby the module 5 generates a plurality of feedback pulse to the control unit 14. The pulses are processed by the control unit 14 to uniquely identify which module 5 is currently generating an active time interval.

The D input to shift register 38 is a logic 0 during the first portion T1 of the active time interval and prevents any selection of the module for firing. During the second portion T2 of the active time interval, the module is "enabled" to be selected, armed and fired by the control unit 14. During T2 the D input to shift register 38 is at a logic 1. The D input logic level is controlled by the 14-bit binary counter 35 whose operation is described in more detail below.

As mentioned previously, during the first portion of the module active time interval, a uniquely identifying pulse is generated in the control unit 14 to identify which module 5 is currently generating an active time interval. The generation of this uniquely identifying pulse occurs as follows: An identification signal generator comprised of the power-up reset circuit 30 and a 4-bit shift register 33 is provided with each firing module 5 for generating a plurality of feedback current pulses to the control unit 14 during the first portion of

a module's active time interval. The power-up reset circuit 30 produces a power reset pulse to clear the logic 18 circuits on receipt of power on the input portion 16 of the firing line.

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The 4-bit shift register 33 functions in a similar way to the shift register 38. That is, if the data input D is at a logic 1, clock pulses will cause a logic 1 to be shifted through the various stages of the register.

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As shown in Figure 2, the clock source for the shift register 33 is the output of the oscillator clock 28. The data input for shift register 33 comes from a 14-bit binary counter 35 which also responds to the clock 28.

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The Q6, or the output of the sixth stage of the binary counter 35, is applied as the data D input to the shift register 33. Thus, a sequence of 1s and 0s will be clocked through the shift register 33 in response to the changes in logic states of the Q6 output of the binary counter 35. A resistor R3 is connected between the Q1 and the Q3 output of the shift register 33 and operates in a manner similar to R2 to create a current increase in the firing line power when there is a difference in the logic states of Q1 and Q3. In accordance with the present invention, resistors R2 and R3, acting in cooperation with the shift registers 38 and 33, respectively, represent a first and a second load connect means for generating current increases on the firing line 3.

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The Q13 output of the binary counter 35 is also applied to signal line 48 as the control input to the solid state by-pass switch 20 which responds to the logic state of Q13 to connect the input portion 16 of the firing line to the output portion 22 thereby powering up the next lower module in the string. The stopping of oscillator

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clock signals on the occurrence of a logic 1 on the Q13 output will thereafter keep the pass-through switch 20 closed until the power on the firing line is removed.

5 As previously mentioned, the active time interval for the module will be determined by the time required to count a predetermined number of clock cycles of the clock 28. For the present invention, the first portion of the module active time interval T1 is measured from the
10 application of the firing line power to the module (the occurrence of the power reset pulse) up to the time that the Q12 output of the binary counter 35 goes to a logic 1. The second portion T2 of the module active time interval is measured by the length of time that Q12 is at a logic 1
15 (the length of time from when Q12 goes to a logic 1 until when Q13 goes to a logic 1).

As shown in Figure 2, the output Q13 of the binary counter 35 is applied as a second enable input to the
20 oscillator clock 28 to also inhibit the generation of any clock signals when Q13 is at a logic 1. The disabling of the clock 28 when Q13 is true (logic 1) indicates that the module active time interval for this module has been completed without this module being selected for firing,
25 and until the power on the firing line is removed, this module will be in a by-passed state.

Having the ability to uniquely identify each module that is generating an active time interval, the control
30 unit 14 can know precisely if the module currently generating an active time interval is the module to be selected and armed for firing. A faulty module which does not generate downhole an active time interval can be detected from the absence of its uniquely identifying pulse envelope

in the sequence of envelopes for the modules when all the modules are sequenced and none is selected for firing.

For the preferred embodiment of the present invention, each module generates 64 current pulses on the firing line during T1. The control unit 14 will count the pulses received during T1 of each module's active time interval to determine the amount of time required by the module to generate the 64 pulses. The time interval thus developed represents the envelope of the feedback identification signal from a particular module. Since the oscillator clock circuits will vary somewhat, each module is likely to produce a pulse envelope that is unique to the module.

To insure that this is the case, each firing module oscillator clock 28 can be slightly altered to produce unique envelope pulses for each module, and this envelope can be measured uphole or downhole to uniquely identify each module. In this way, there is no need to count how many modules have been connected to the firing line in the selection sequence. The uniquely identifying pulse determines when a given module is connected to the firing line and generating an active time interval. Isolated noise pulses on the firing line will not generate an error condition because 64 pulses must be received.

While 64 pulses is the ideal number, it is possible to permit a small band or variation of total pulses received and still result in a unique identification of the module. Thus $64 \pm n$ pulses are permitted and still be able to uniquely identify a given module.

Connected to the reset input of the shift register 33 is the Q12 output of the binary counter 35. Thus, the shift register 33, acting in combination with the Q6

output of the binary counter 35 and the clock 28, produces a predetermined number of short duration current pulses onto the firing line 3 until such time as Q12 goes to a logic 1. When Q12 goes to a logic 1, the shift register 33 is reset and inhibited from further generating any current pulses on the firing line. In addition to resetting the shift register 33, the Q12 output of binary counter 35 is also applied as the data D input to the shift register 38 as the signal labeled ENABLE.

Turning now to Figure 3, a timing diagram of various signals within the single-wire perforating system according to the present invention is shown. For the signals illustrated in Figure 3, the third module down from the control unit 14 is the module to be selected.

Figure 3 illustrates the first and second portions of each module active time interval, T1 and T2, respectively. During the first portion T1 of each module active time interval, 64 current pulses are generated in the current signal on the firing line 3. For purposes of illustration, the time interval required to generate the 64 pulses by each of the modules is different so that the width of the resulting envelope pulse, labeled t1 through t4, are different and each pulse uniquely identifies its associated module. The noise pulses occurring between module No. 1 and module No. 2 results in a narrow pulse envelope for an identification pulse, and because it didn't contain the correct number of current pulses, it will be disregarded by the control unit 14 and reported to the surface for possible action.

Since module No. 3 is the module to be selected, the control unit 14 will generate the module selection control signal and the sequence of three arming selection control signals during the second portion T2 of the module active time interval. These control signals are applied as voltage pulses on the power voltage of the firing line. The first control signal received during the second portion of module No. 3's active time T2 will select the module for firing and thereby terminate further generation of the module active time. This, in turn, prevents further sequencing of any lower modules.

With receipt of a selection control pulse during T2 of the module active time for module No. 3, the module will enter into a selected state during which it can be armed for firing if the safeguard feedback detection sequence determines that the modules are operating properly. This safeguard detection sequence begins with receipt of the first arming control signal by the arming circuit. As previously discussed, the arming circuit produces the predetermined current pulse increase in the firing line current illustrated in Figure 3 as the arming status pulse. The second arming pulse will be issued by the control unit 14 to remove the arming status current pulse if the proper value for the current increase was detected.

If the proper value for the arming status pulse was detected, the control unit 14 proceeds to issue a third arming control signal to cause the arming switch 21 (see Figure 2) to close connecting the detonator 24 to the firing line 3. With the closure of the arming switch 21, the control unit 14 can then issue a firing pulse on the firing line at any time it desires to fire the module. Rather than detonating the module, however, the control

unit 14 can reset the modules to select a different module by simply removing the power on the firing line without generating a firing pulse. This safety feature can be used to sequence through each of the firing modules to
5 determine if all modules are operating properly, and to further define the unique identifying envelope for each pulse as a function of the given operating conditions that the gun is currently experiencing, since temperature variations encountered downhole may cause fluctuations in
10 the time base in each firing module. A time base variation will change the time required to generate the 64 pulses that uniquely identifies the module.

As a redundant check to the safeguard arming status pulse during the arming sequence, the control unit 14 can
15 determine if the modules are operating as expected by measuring the amount of current increase as each module is added to the firing line. The increase in the firing line current as each module is added to the firing line is
20 illustrated in Figure 3 at the start of each module active time interval as a step function.

It is one of the important features of the present invention that redundant safeguard detection methods are
25 provided for determining faulty conditions or failures in the firing system before any attempt to fire the guns is made. These failures may be classified as failures resulting in the firing of a wrong gun which could be noticed or the failures which cause the undetected firing
30 of a wrong gun.

As previously discussed, the response from every module during the first portion of the module's active

time interval is a train of 64 feedback current pulses. The control unit 14 detects these feedback pulses and forms the envelope of the pulse train to uniquely identify the modules as they are connected to the firing line. To
5 increase the immunity against noise on the firing line 3, the 64 pulses generated during the first portion of each module active time interval is recognized as correct if the number of pulses detected in the sequence is within a
certain number of the correct number. Thus, false pulse
10 trains, such as the noise pulses illustrated in Figure 3, will be discarded, and the surface equipment could be informed about their occurrence.

A safeguard to the determination that the modules are
15 functioning properly is present in the active time intervals of the various modules. The envelope of the feedback pulses during the first portion of the active time interval is a measurable time interval of approximately half the active period of the module. The control unit 14 is built
20 to accept a wide range of active period values and is able to measure them with high resolution. Every module 5 in the gun string 10 can be individualized through a dispersion in their various clock 28 frequencies. Even if the frequencies are not made different, the frequency distribution of the various frequencies represents a random
25 process where the difference between adjacent modules may not always be measurable, but the probability of this condition to leave a failure undetected is sufficiently low. Otherwise, the modules could be trimmed to different
30 values of their active periods and placed sequentially in the string.

Since the present invention is able to sequence through each of the modules without firing any module, it

is possible to measure, before the guns are fired, the time intervals for each of the modules. These values can form a reference table of active times versus module position which can be used later to verify the selections during the perforation operations.

Another safeguard detection system involves the measurement of the line current on the firing line 3. The control unit 14 includes a high resolution measurement of the current supplied to the firing line. After a module is selected, the current on the firing line is proportional to the number of modules connected to the line, and therefore, indicative of the module selected.

The total current drain produced by all the firing modules connected to the firing line may not be precise enough to indicate the number of modules, but the single addition or subtraction of a module on the firing line produces a predictable change in the current. With the perforating string 10 downhole and before firing the guns, reference values of supply current can be measured with selection cycles of progressive length. In other words, a selection cycle to select module No. 1 followed by a selection cycle for module No. 2, etc., can be run to determine how this increase in firing line current occurs for each module. These measurements can be made simultaneously with the identification pulse measurements.

The verification of the active time interval and line current is a safeguard in situations where a failure reduces the active period of a module to zero and the failed module powers up together with the next lower module, and is by-passed without being accounted for.

In most perforation systems where the present invention can be applied, the firing of the gun destroys the electrical line passing through it. This situation is inconvenient since it restricts the arbitrary nature of the selection, but is helpful in finding the position of the last fired gun. This can be accomplished by counting the modules still able to communicate with the control unit 14.

The number of interconnected modules is measured by a selection cycle of unrestricted length. The control unit 14 will count the feedback pulse trains, and therefore the number of modules. As the last module is by-passed, the measurement of the supply current will indicate the condition of the line below the last unfired gun. The same measurement can locate any failure in the wiring between modules. The control unit 14 can detect an open or short circuit in the line and determine up to which gun the string is still operable.

After the selection cycle in which a module is selected and armed for firing, only the active module should be able to forward the firing current to the blasting cap. But any of the by-passed modules could be defective and remain "active" after being by-passed. The module with the faulty circuitry could fire in parallel with the selected one, and eventually go undetected. As a safeguard against this failure, the selected module is not ready to accept the firing current immediately after the selection control signal is applied to the firing line 3, but requires an arming sequence of several arming control signals.

As previously discussed, arming is implemented in accordance with the present invention with three additional control pulses on the firing line 3 similar to the one used in the selection process. Only the selected
5 modules should be able to receive these pulses.

The first arming pulse will increase by a fixed amount the supply current drained in the active module with the second pulse returning the current to its previous value. If the increase in current was within
10 acceptable limits, a third pulse will finally close the arming switch 21 between the detonator or blasting cap 24 and the firing line 3. Simultaneously, or sometime after the third arming control pulse, the control unit 14 will
15 connect a firing capacitor to the firing line and produce the firing current.

If a defective module is placed in any intermediate arming stage after the selection, including the state
20 where the switch to the blasting cap is closed, the measurement of the line current before and during the arming sequence will detect this faulty condition.

Summarizing the present invention, a single-wire
25 selective perforating gun system is disclosed in which a plurality of identical firing modules are connected, one to another, to form an elongated assembly suitable for lowering into a well borehole. Included in the assembly is a control unit for generating power and firing line
30 signals to each of the firing modules as each module is connected, one at a time, in a sequence to the control unit.

Each of the firing modules generates internally an
35 active time interval during which the module can be

selected and armed for firing by the control unit. The active time interval begins when power is applied to the module by connection of the module to the firing line. Each firing interval has a first and a second portion.

5 During the first portion, a unique identification pulse is generated in the control unit to indicate that a particular module from among the plurality of modules is connected to the firing line and is generating an active time interval. In this way, the control unit is able to determine when a particular module is available for selection.

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During the second portion of the module active time interval, the control unit may select a module for firing by issuing a selection control pulse onto the firing line.

15 Pulses on the firing line during the first portion of the active time interval are disregarded by the module since a module may only be selected and armed during the second portion of the time interval.

20 Once a module is selected, the control unit will issue a sequence of three arming signals to arm the module. The first and second arming control pulses will produce a current pulse increase on the firing line power of a predetermined amplitude to indicate to the control unit if one and only one module is responding to the arming sequence. If the current increase is within acceptable limits, the control unit will then issue a third arming control signal to connect the detonator of the charge in the module to the firing line. Once the

25 module is armed for firing, the control unit 14 can issue a firing pulse to detonate the charge or can remove the firing line power to reset all of the modules and permit the selection process to be repeated to select a different module.

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-34-

In describing the invention, reference has been made to its preferred embodiment. However, those skilled in the art and familiar with the disclosure of the invention may recognize additions, deletions, substitutions or other modifications which would fall within the perview of the invention as defined in the appended claims. For example, the invention has been described with reference to a single firing line 3 which carries both power and control signals between the control unit 14 and the plurality of firing modules 5. It will be obvious that the advantages of the present invention may be obtained by using more than one signal line to carry power and control signals from the control unit to the modules. A single line to carry the control signals for selection and arming separate and apart from the firing line power and feedback signals could be employed where the signal lines are segmented in the same way as disclosed herein.

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WHAT IS CLAIMED IS:

1. In a single-line selective perforating system having a single firing line for electrically connecting a firing control unit to each of a plurality of shot modules, one at a time in a predetermined sequence, where each module is adapted for connecting the connected control unit to a next module, a method of selecting a module for firing characterized by the step of connecting each module one at a time in the predetermined sequence to the firing line under control of module active time intervals internally generated in the modules, where each module generates its active time interval in response to being connected to the firing line with the next module in the sequence automatically connected to the firing line at the end of the active time for the last connected module if that module was not selected for firing during its active time interval.

2. The method of claim 1 characterized in that each module receives on the firing line both power and firing signals from said control unit, and comprising the steps of:

(a) generating internal to each module in response to receipt of the power signals on the firing line

(i) a module active time interval during which the module may be selected for firing by a selection control signal from the control unit, and

(ii) an identification pulse for transmission over the firing line to the control unit to indicate that a next module has been connected to the firing line; and

(b) automatically connecting the firing line to the next module in the sequence at the end of the module active time for the last connected module if that module was not selected for firing during its active time.

3. The method of claim 2 characterized in that the step of generating an identification pulse comprises generating during the active time interval for each module an identification pulse which uniquely identifies the modules.

4. The method of claim 1, 2 or 3 characterized in that the step of connecting each module to the firing line comprises the steps of:

- (a) applying power to the firing line in the form of voltage and current for powering the modules connected to the firing line;
- (b) generating a module active time interval in the module last connected to the firing line power;
- (c) controlling at the end of each module active time interval a pass-through switch to pass the firing line power to the next module in the sequence; and
- (d) repeating steps (b) and (c) until the module to be selected is generating an active time interval.

5. The method of claim 2 or 3 characterized in that each module active time interval includes

- (a) a first portion during which the module generates and applies the identification pulse onto the firing line, and
- (b) a second portion during which the module is enabled to receive a selection pulse on the firing line from the control unit to select the module for firing.

6. The method of claim 2 characterized in that the step of generating the identification pulse includes the step of generating a current increase in the firing line power where the amplitude of the firing line current change lies in a predetermined range.

7. The method of claim 2 or 6 characterized in that the identification pulse for each module must occur within a predetermined time window measured from the occurrence of the last identification pulse.

8. The method of claim 1 characterized by the steps of:

(a) generating an arming pulse to the active module when that module is to be armed for firing; and

(b) connecting the detonation portion of the shot in the selected module to the firing line when the module is armed for firing by the arming pulse whereby a firing pulse on the firing line can detonate the selected shot.

9. The method of claim 3 or 4 characterized in that the step of generating the identification pulse which uniquely identifies the module includes the step of generating a predetermined number of current pulses on the firing line where the time interval to generate the current pulses represents the identification pulse.

10. The method of claim 9 characterized by the step of providing each module with a different predetermined time base for generating the identification pulse whereby the time intervals of the identification pulses for the modules are each different.

11. The method of claim 10 characterized by the step of connecting the shot in the selected module to the firing line when the module is selected for firing whereby a firing pulse on the firing line can detonate the selected shot.

12. The method of claim 11 characterized by the step of connecting the shot to the firing line includes the steps of:

(a) generating a predetermined increase in the firing line current in response to a first arming control pulse, the predetermined increase in current indicating that a single module is responding to the arming control pulses;

(b) removing the predetermined current increase in the firing line current in response to a second arming control pulse; and

(c) connecting the shot to the firing line in response to a third arming control pulse generated if the predetermined change in firing line current is within acceptable limits.

13. The method of any one of the previous claims characterized by the step of grounding the shot in each module that was connected to but not selected by the control unit.

14. The method of any one of the previous claims characterized by the step of generating a power reset in each module when each module is connected to the firing line thereby initiating each active time interval.

15. The method of claim 5 wherein the first and second portions of each active time interval are equal in length.

16. The method of any one of the previous claims characterized in that each module connected to the firing line but not selected remains connected to the firing line in an inactive state, and where the modules in an inactive state may be reset to once again be sequenced by momentarily removing the power from the firing line

17. A single-wire selective perforating system for selectively detonating the charges in a plurality of firing modules, one at a time, comprising:

(a) a control unit operatively connected to the modules by a single firing line which carries both power and control signals between said control unit and the modules; and

(b) a plurality of selectable firing modules vertically connected one to another to form an elongated assembly suitable for lowering into a well borehole, the assembly including said control unit, with each module,

(i) containing at least one charge and where each module is automatically connected one at a time to the firing line in a predetermined sequence to receive power therefrom, and

(ii) in response to receipt of power on the firing line, internally generates a module active time interval during which the module and its charge may be selected for firing by said control unit, each module not selected for firing during its active time interval automatically connecting the firing line to the next module in the sequence.

18. The system of claim 17, characterized in that each module, in response to receipt of power on the firing line, then generates during the active time interval an identification signal which uniquely identifies the module.

19. The system of claim 17 or 18 characterized in that said control unit includes:

(a) a means for detecting the amount of power current present on the firing line, thereby to detect when a module has been connected to the firing line; and

(b) a means for generating control signals on the firing line including

(i) the selection control signal for selecting the module to be selected for firing,

(ii) a sequence of arming control signals for connecting the charge in the selected module to the firing line, and

(iii) a firing control signal for detonating the charge in the module selected for firing.

20. The system of claim 19 characterized in that the firing line in each of said firing modules includes an input and an output portion, each said firing module comprising:

- (a) an identification signal generator responsive to the receipt of power on the input portion of the firing line for generating the identification signal to said control unit indicating that a particular one of said modules has been connected to the firing line;
- (b) a module active time interval generator responsive to said identification signal generator for generating the module active time interval during which the module may be selected for firing;
- (c) a stop pulse detector responsive to the selection signal on the input portion of the firing line and to said time interval generator for terminating the generation of the module active time interval and for terminating further module selection;
- (d) an arming circuit responsive to the sequence of arming control signals and said stop pulse detector for connecting the charge in the module to the firing line thereby arming the module for firing; and
- (e) a pass-through switch responsive to said module active time interval generator for connecting at the end of the module active time interval the input portion of the firing line to the output portion thereby connecting power to a next firing module in the assembly.

21. The system of claim 18, 19 or 20 characterized in that said identification signal generator comprises:

- (a) a power reset circuit responsive to the receipt of power on the input portion of the firing line for generating a power reset pulse to initiate the active time interval for the module; and

(b) a first load connect means responsive to the power reset pulse for generating a predetermined number of pulses on the firing line where the time required to generate the predetermined number of pulses represents the identification signal which uniquely identifies the module.

22. The system of claim 17 characterized in that the firing line in each of said firing modules includes an input and an output portion, each said firing module comprising:

(a) an identification pulse generator responsive to the receipt of power on the input portion of the firing line for generating a pulse indicating that the module has been connected to the firing line;

(b) a module active time interval generator responsive to said identification pulse generator for generating the module active time interval during which the module may be selected for firing;

(c) a stop pulse detector responsive to a selection pulse on the input portion of the firing line and to said time interval generator for terminating the generation of the module active time interval, and for connecting the charge in the module to the firing line thereby selecting the module for firing; and

(d) a pass-through switch responsive to said module active time interval generator for connecting at the end of the module active time interval the input portion of the firing line to the output portion thereby connecting power to a next firing module in the assembly.

23. The system of claim 20 or 21 characterized in that said identification pulse generator comprises:

(a) a power reset circuit responsive to the receipt of power on the input portion of the firing line for generating a power reset pulse to initiate the active time interval for the module; and

(b) a load connect means responsive to the power reset pulse for increasing the current on the firing line, the current pulse increase in firing line current representing the identification pulse of the module.

24. The system of claim 23 characterized in that said firing module active time interval generator comprises:

(a) a clocking oscillator for generating a digital time base clocking signal; and

(b) a binary counter responsive to said stop pulse detector and the clocking signal for counting a predetermined number of clock pulses to determine the length of the module active time interval, said counter

(i) outputting a first signal when a first portion of the time interval has occurred, and

(ii) outputting a second signal when a second portion of the time interval has occurred.

25. The system of claim 24 characterized in that

(a) the identification signal is generated during the first portion of the time interval, and

(b) the module is enabled to receive a selection pulse during the second portion of the time interval.

26. The system of claims 24 or 26 characterized in that said stop pulse detector comprises:

(a) a means for detecting an increase in voltage on the input portion of the firing line, an increase in voltage during the second portion of the active time interval representing the selection pulse;

(b) a disabling means responsive to the detecting means and to said module time interval generator for disabling the clocking signals to said binary counter and for generating a firing switch signal if a selection pulse is detected by said detecting means during the second portion of the module active time interval; and

(c) a controllable switch responsive to the firing switch signal for connecting the input portion of the firing line to the charge in said firing module.

27. The system of claim 26 characterized in that said stop pulse detector comprises:

(a) a means for detecting control signals on the input portion of the firing line, a control signal received during the second portion of the active time interval selecting the module for firing; and

(b) a disabling means responsive to the detecting means and to said module time interval generator for disabling the clock signals to said binary counter thereby terminating further module sequencing if a selection pulse was received during the second portion.

28. The system of claim 27 characterized in that the sequence of arming signals includes a first, second and third arming control signal, said arming circuit including:

(a) a second load connect means responsive to said stop pulse detector and to the first and second arming signals for generating a pulse of predetermined magnitude to said control unit to indicate that only one module is responding to the arming signals; and

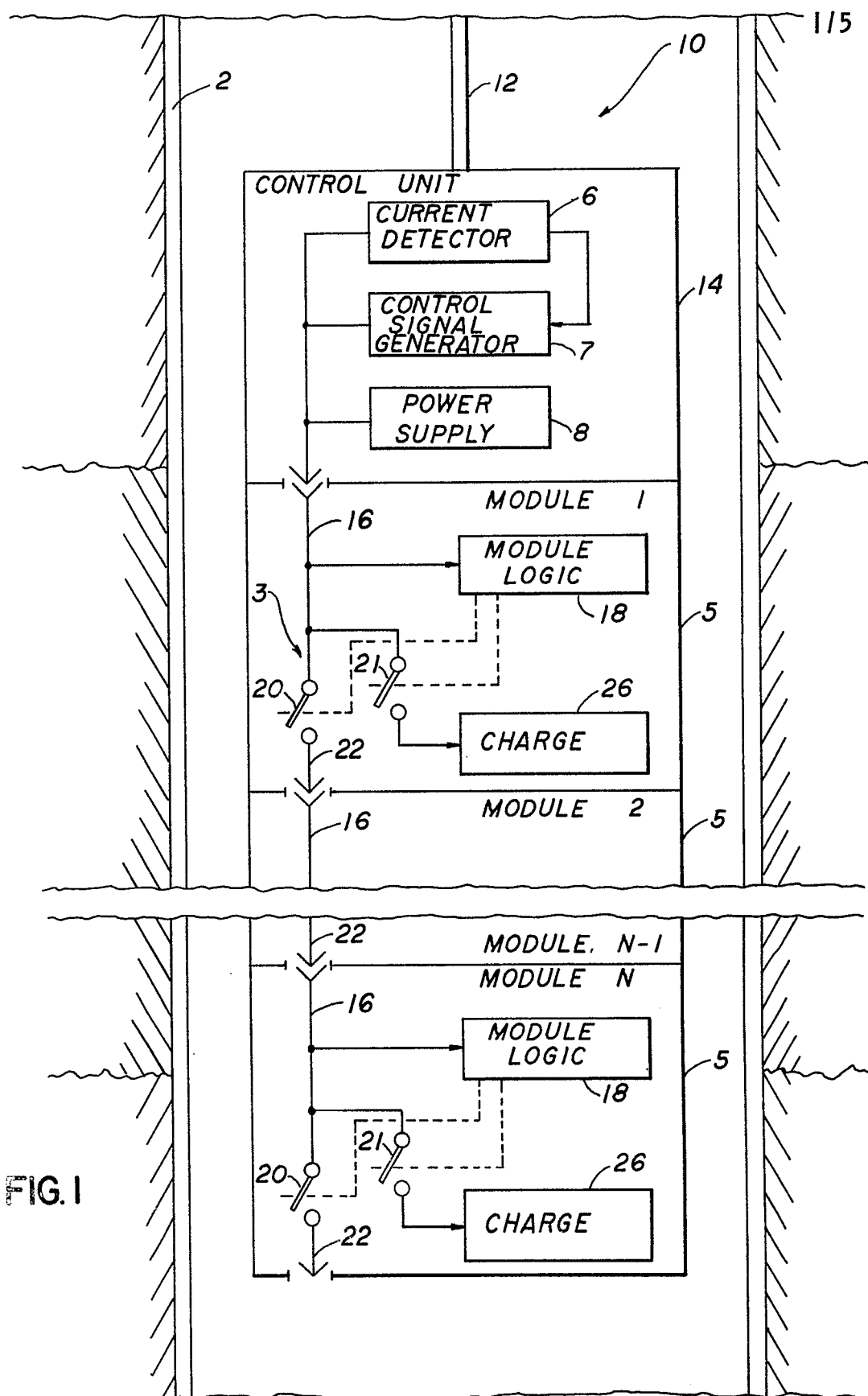
(b) a charge connect switch responsive to the third arming signal and said stop pulse detector for connecting the input portion of the firing line to the charge thereby arming the module for firing.

29. The module of claim 26 characterized in that said stop pulse detection means further includes a zener diode connected between the firing line and said controllable switch for blocking any voltage pulses of less than a predetermined voltage from reaching the charge when the module has been selected for firing, the firing pulse having a voltage amplitude greater than the predetermined voltage.

30. The method of any one of claims 17 to 29 characterized by the steps of:

(a) applying to the firing line electrical power having voltage and current of sufficient magnitude to power the modules but without sufficient power to fire a shot; and

(b) generating during a module active time interval a selection pulse if the active module is to be selected whereby the module is selected for firing by a firing pulse of sufficient power on the firing line to detonate a shot.



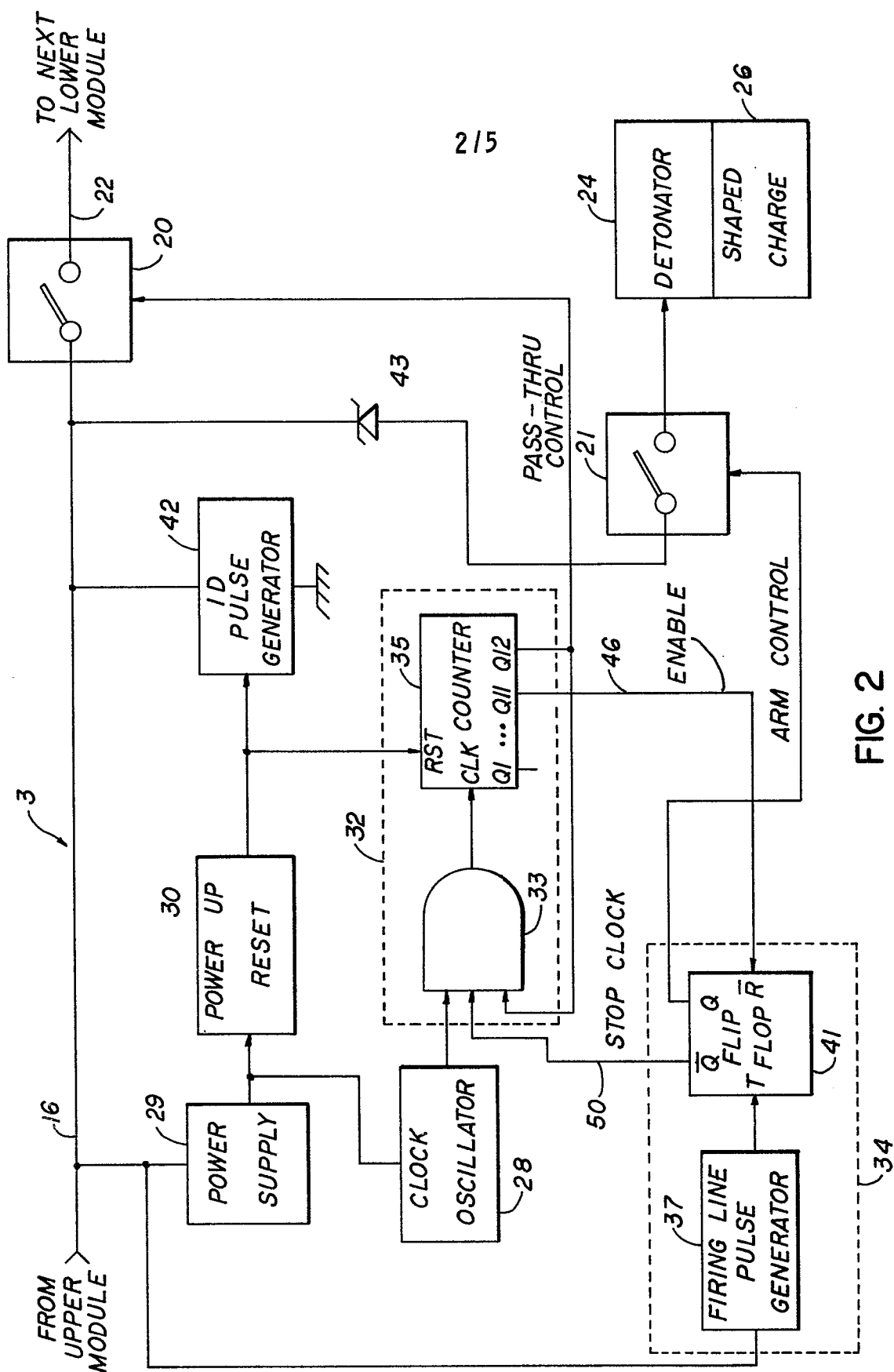


FIG. 2

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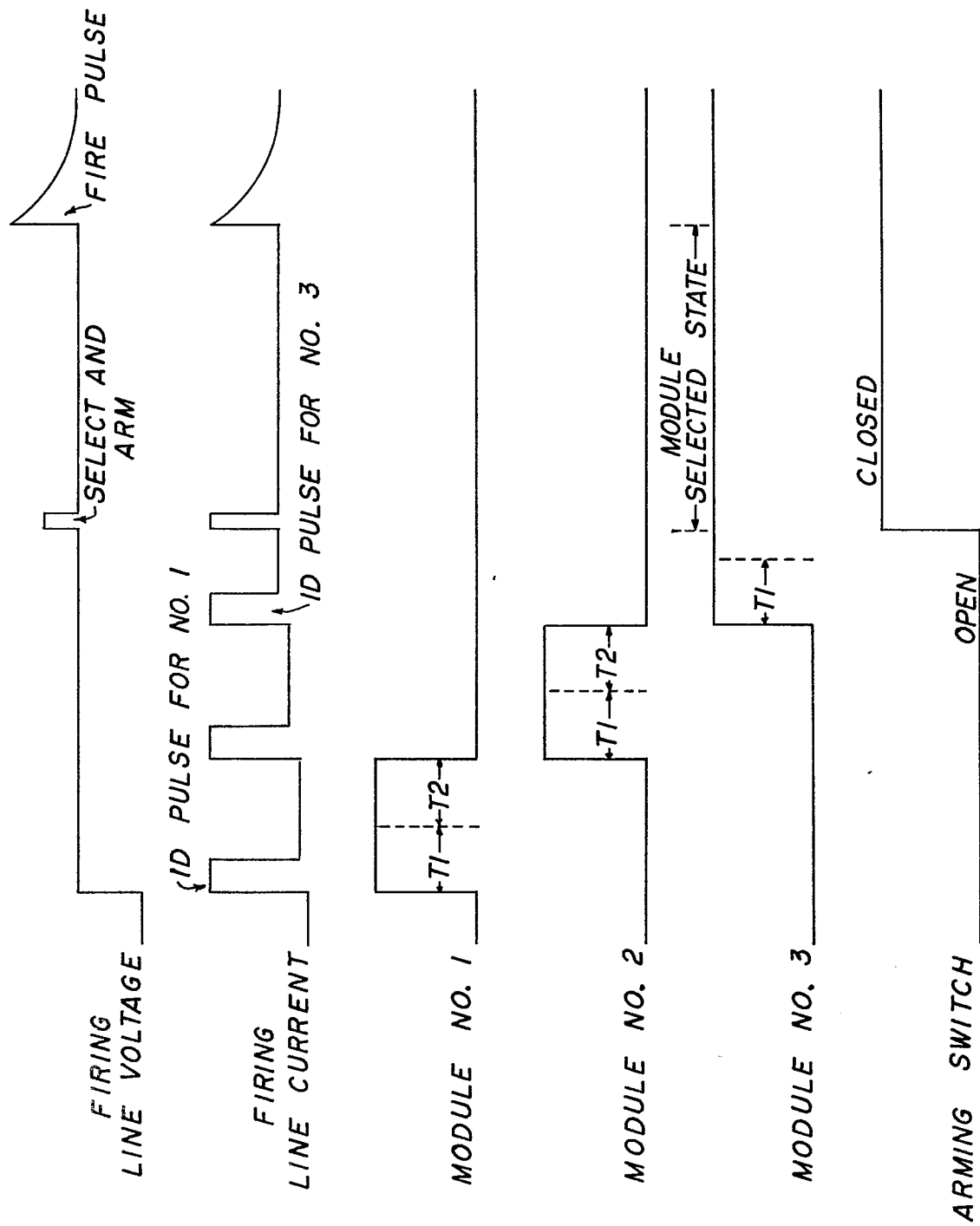


FIG. 3

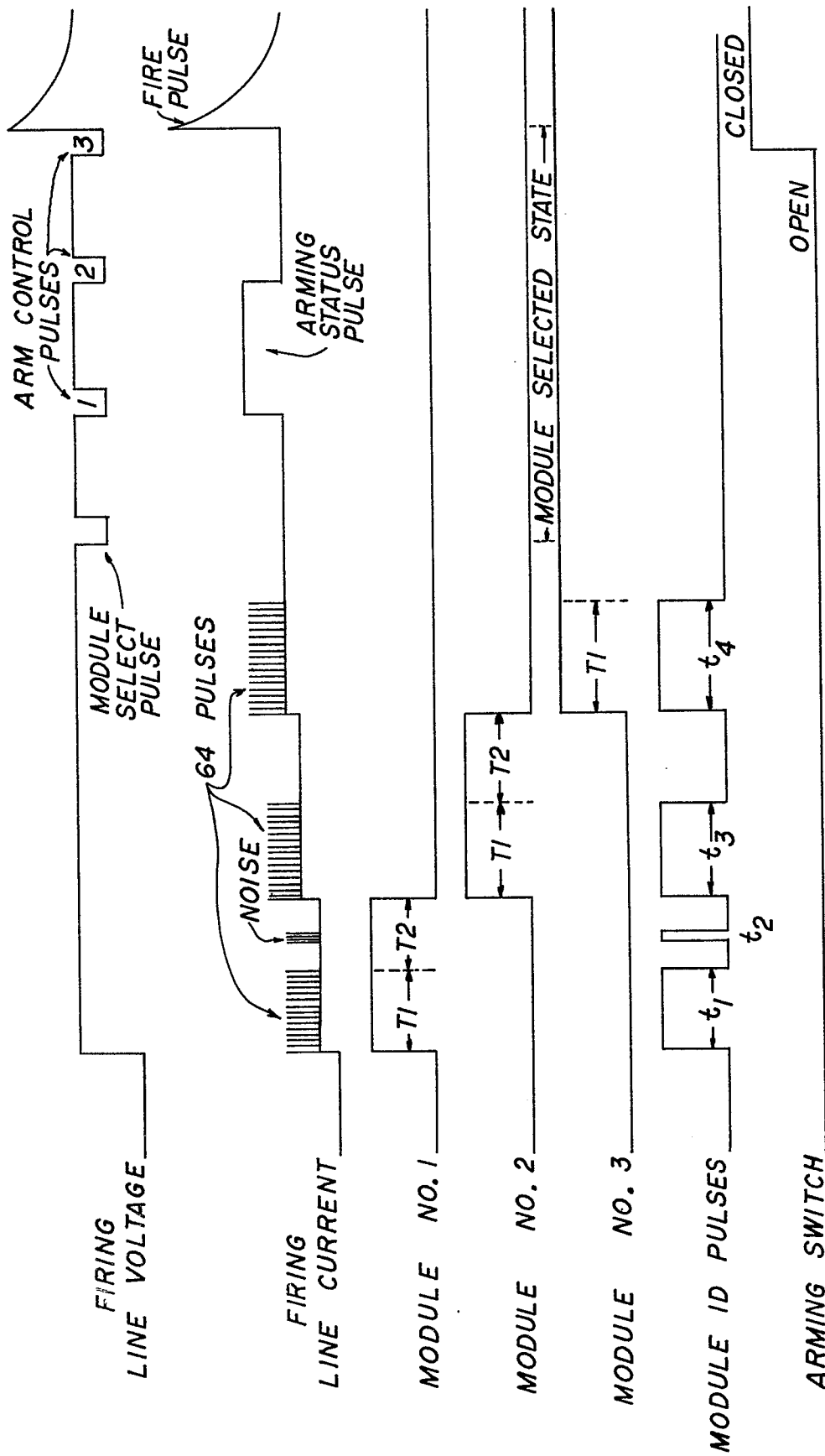


FIG. 4

FIG. 5

