June 27, 1967 G. T. BOOP 3,327,792

JET PERFORATING GUN

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Fig.1

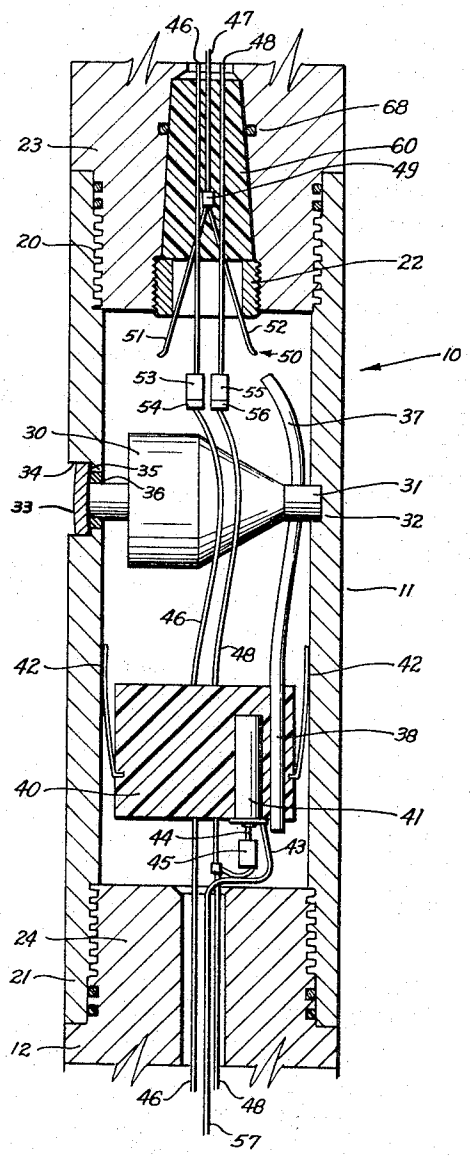
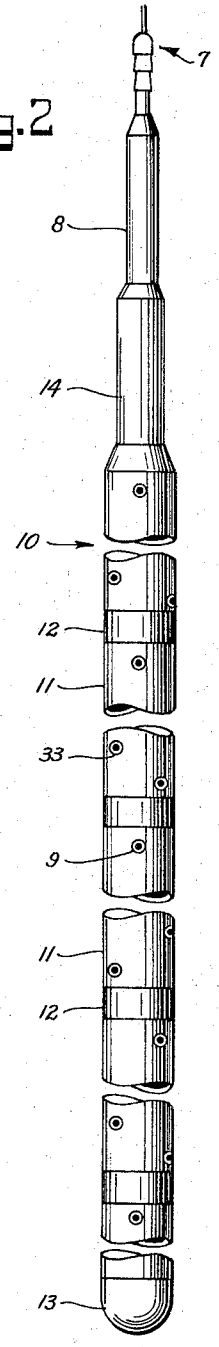


Fig.2



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Fig.3

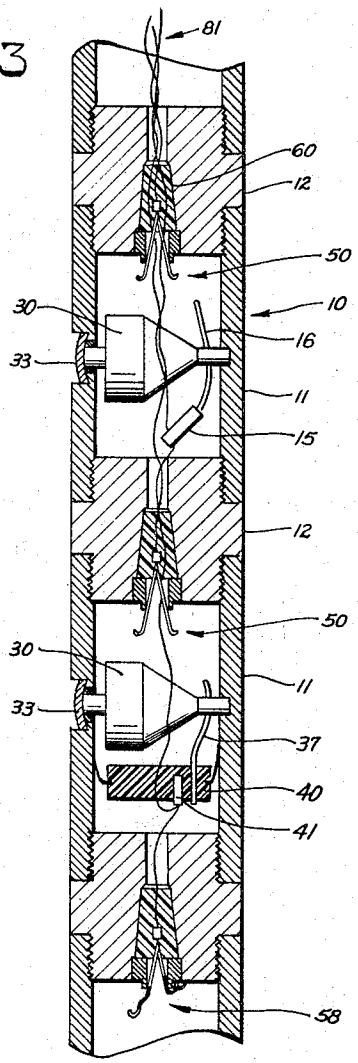


Fig.4

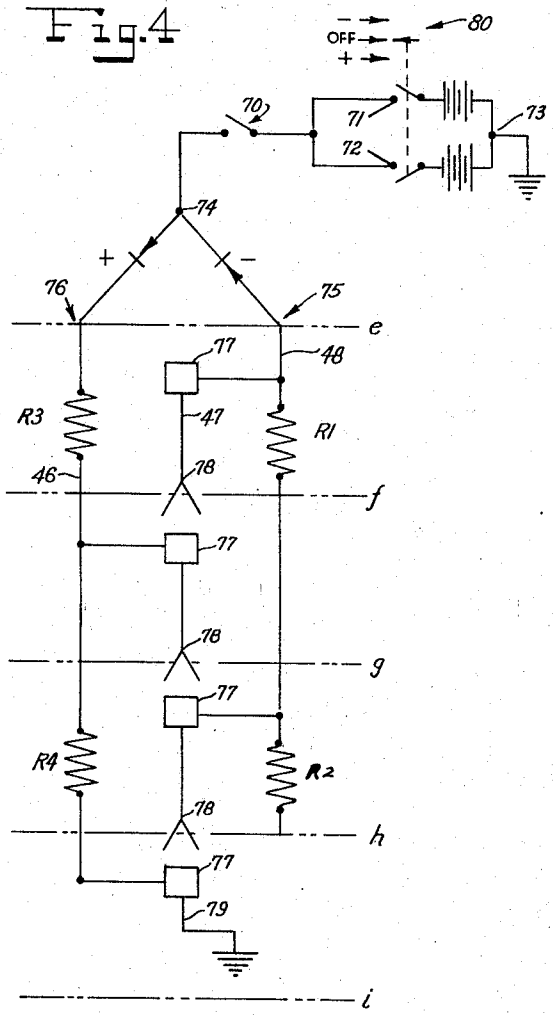
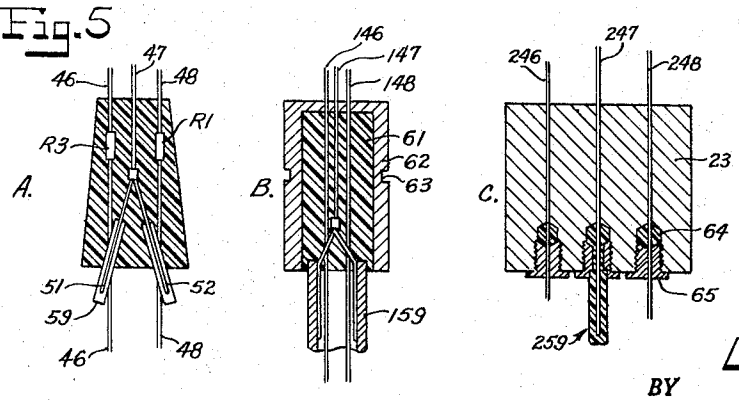


Fig.5



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JET PERFORATING GUN

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ABSTRACT OF THE DISCLOSURE

A select fire jet perforating gun assembly including two parallel electric circuits, wherein each circuit alternately fires a charge carrier, and each charge carrier must be detonated in order to arm the next adjacent charge carrier. The arming means includes a molded plastic seal having a heat velocity switch rigidly attached therein during the molding process. The detonation of a charge carrier causes the heat switch associated therewith to arm the next adjacent charge carrier.

This invention relates to a novel concept in jet perforating guns, in which a multiplicity of guns may be selectively fired in consecutive order using a single conductor control wire from ground level to the gun head.

Briefly stated, one purpose of the present invention is to provide a novel control circuitry of the combination utilizing a simple two wire circuit system to form two circuit legs to fire alternately arranged charge carriers under the control of a single wire. Each charge carrier depends upon its proper detonation to arm the next above adjacent charge carrier.

Another purpose of the invention is to provide a novel arming device that depends upon the tremendous explosive energy and heat released in detonation or firing of one adjacent charge carrier to arm the next adjacent unfired or loaded charge carrier.

Still another purpose of the present device is to provide a multi-purpose seal means that will retain the arming device under the tremendous temperature and pressure conditions encountered during detonation of a charge carrier, while retaining other vital circuit components in suitable working condition.

Other objects of the invention will become apparent from a reading of the entire disclosure.

Select fire multi-perforating jet guns are known in the wireline field. Particular reference is made to Patent Number 3,173,992, which is one of patentees previous contributions to the wire line field, wherein a single conductor operates a motor driven selector switch which in turn actuates a multiplicity of charge carriers.

One advantage of the present disclosure over the prior art is the requirement of only two insulated wire connections between adjacent guns, a greatly simplified heat sensitive arming switch which operates by both direct and indirect grounding, and the elimination of all mechanical switch means within the charge carrier other than the before said single arming means as will be more fully described in the following body of the specification.

In the drawings:

FIGURE 1 is a vertical section through one of the charge carriers showing the charge assembly therein.

FIGURE 2 is an elevation showing an assembled jet perforating gun.

FIGURE 3 is a diagrammatical and partly sectional view of a portion of a jet perforating gun.

FIGURE 4 is a schematical representation of the circuitry used to control the firing sequence of the jet perforating gun.

FIGURE 5 shows a sectional view of three modifications of a combinational seal and heat velocity switch that may be used in a jet perforating gun.

Looking in detail now at the drawings:

FIGURE 1 shows a charge carrier **11** which is fabricated from a cylindrical tube internally taper threaded at each end to form upper and lower boxes **20**, **21**; which in turn receive the similarly threaded pins **23**, **24** of connector or sub **12**.

The assembled relationship of the entire mechanism including the charge carriers **11** and subs **12** is illustrated in FIGURE 2 wherein a wire-line having a centrally located insulated single control wire embedded therein is attached as at **7**; the details of which are well known in the art. Numeral **8** represents an accessory wire-line tool such as a collar locater or orientation device, and forms no part of the present invention. Numeral **14** is the gun head in which portions of the circuitry may be conveniently located if desired. The assembled cable connector **7**, supplementary wire line device **8**, gun head **14**, charge carriers **11** and subs **12** are assembled into a unit **10** with a guide plug **13** at the lower extremity to facilitate its placement into the well.

FIGURE 3 shows several of the charge carriers **11** in assembled and operative relationship. The various charge carriers **11** are operatively connected by the subs **12**, and seal **60** is centrally and rigidly affixed to sub **12**. The three wires at **81** represent the wires **46**, **47**, **48** the details of which are best seen in FIGURE 1. The wires lead through seal **60** where they travel on to the various components of the device as will be more fully discussed later on.

Beginning with uppermost sub **12** there is seen in FIGURE 3 a heat switch rigidly affixed in seal **60** as indicated by numeral **50**. The second or centrally located sub **12** of FIGURE 3 has a similar seal and heat velocity switch **50**. The lower or third heat velocity switch **58** has been triggered, or subjected to the firing of the bottom charge carrier (most of the details of which are missing). Thus it is apparent that FIGURE 3 illustrates a portion of the perforating gun of FIGURE 2, in which the bottom-most charge carrier has been discharged, triggering or activating its associated heat switch **58**. The adjacent charge carrier and the next above charge carrier has not been discharged.

Looking now to the details of FIGURE 4, there is seen a battery operated circuit having two circuit legs **75** and **76** branching from junction **74**. Lines *e*, *f*, *g*, *h*, and *i* indicate the relative position of the subs **12** (comparing FIGURES 3 and 4) and the circuit portions indicated by numerals *e–f*, *f–g*, *g–h*, and *h–i* indicate that portion of circuitry normally located within a charge carrier **11**. Numeral **77** represents a cap, Primacord, and shaped charge (elements **41**, **37**, and **30**). The heat velocity switch **78** is shown extending into each adjacent charge carrier in operative position to be triggered. Beginning with switch assembly **80** there is shown two batteries with reversed polarity connected to a common junction **73** which leads to a ground connection. A single battery with proper switching arrangement may optionally be employed to attain this same result, if desired. Switch operator **80** actuates the two switches **71**, **72** which comprise a normally open and normally closed switch arrangement, and are connected together to safety switch **70**.

Two diodes, or rectifiers, are connected with reversed polarity at **74** to form circuit legs **75**, **76**. Circuit leg **75** fires alternate charges **77** through wire **48**; and circuit leg **76** fires alternate charges **77** through wire **46**. The resistors R1, R2, R3, and R4 are preferably located inside the seal **60** in pairs, as illustrated in FIGURE 5A at R1 and R3.

In operating the circuitry of FIGURES 1 through 4, direct current (D.C.) is used as the power source, as is evident from the embodiment of FIGURE 4.

Circuit operation

With safety switch **70** in closed position, and switch operating handle **80** pushed down to close switch **71**, current will flow to junction **74** then to leg **76**, through R3, wire **46**, R4, through charge **77**, and through wire **79** to ground. Current will not flow through leg **75** since the diode of this leg is arranged opposite in polarity to the diode of leg **76**. Current will not flow to any of the charges **77** in leg **76** except the charge **77** in carrier *h–l* since the only path available to current flow is through conductor **79** to ground, which detonates charge **77** (by exploding an electrical cap, which explodes the Primacord, which sets off the shaped charge; all of which are represented by **77**).

Detonation of charge carrier *h–i* triggers heat velocity switch **78** located therein thus arming the next above charge in charge carrier *g–h*. Should switch **70** be closed again, no further detonation will occur for the wire to charge **77** will be destroyed having been fused or burned away up into the seal that is located in the sub between charge carriers. However, detonation has caused the heat velocity switch in charge carrier *h–i* to be actuated thus arming the charge in charge carrier *g–h* which will allow its associated charge **77** to detonate upon reversal of polarity switch selector **80**, which reversal of polarity will allow current now to flow down **75**, but not down leg **76** because of the relationship of the diodes in each leg. Upon reversal in position of polarity selector switch **80**, closure of switch **70** will cause detonation of charge **77** located in charge carrier *g–h*, thus arming the next above charge, which may be detonated by another reversal by the polarity switch **80** (to its original position) to enable current to flow down leg **76** only. This sequence of manipulation may be carried out until all of the charges have been fired. There is obviously no limit to the number of charges that may be fired or detonated by the system. For clarity, only four charges **77** associated with four charges carriers have been shown in FIGURE 4.

FIGURE 5 shows three seals A, B, and C, with a heat velocity switch associated therewith. In the seal shown in FIGURE 5A, two resistors R3 and R1 are shown embedded therein along with the wires **46** and **48** for the two circuit legs. Conductor **47** is attached to the heat velocity switch within seal **60** and is shown in FIGURE 5A as having legs **51**, **52** with insulation thereon.

The seals in FIGURE 5A, B, and C are fabricated with the heat velocity switch, two wires, and two resistors molded in place. The seal is made of a resilient, nonconducting material such as a synthetic resin which is either thermosetting or alternatively has a high heat resistance of thermoplastic. Polyester, such as used in conjunction with fiberglass fabric, has been found to be suitable for molding the seal.

The size of the three wires **46**, **47**, **48** entering seal **60** of FIGURE 5A is not critical, and a copper wire of 0.020 inch diameter size having 0.011 inch thick "Teflon" insulation for example, has proven satisfactory.

The heat velocity switch of FIGURE 5A is shown rigidly molded in seal **60**. The switch is formed of a single length of "piano wire" bent in the center to form two legs **51**, **52** to include an acute angle of about 30°. The apex or center of the heat switch is electrically connected to insulated wire **47** which wire is of the same specifications as wires **46** and **48**. Legs **51** and **52** are entirely coated with an adhering sheath of "Teflon" (polytetrafluoroethylene). The heat velocity switch may alternatively be coated with other insulating substances, such as the polyesters, the only requirement being that the coating form an electrical insulation in the presence of salt water, yet have the capacity to be destroyed upon detonation of the associated shaped charge so as to allow the

wire to contact a metallic wall of the device while at the same time being positioned so as to become a conductor when immersed in liquid thereby providing an alternative ground connection for the cap in the circuitry.

Resistors R3 and R1 are placed inside the seal in order to prevent malfunction should a leak occur in any single charge carrier. This novel arrangement of the resistors will prevent a misfire of the entire system should any upper charge carrier inadvertently become filled with fluid; however, all of the charges could not be fired under such an adverse condition since the leaky carrier would constitute an open circuit since its heat switch would remain inactivated.

FIGURE 5B shows a modified seal and heat velocity switch, which, in this embodiment, is held away from any grounding structure by cylindrical insulator **159**, this insulator **159** may be any suitable electrical insulation means having sufficient strength to retain the spring loaded heat switch legs in compression, as adequately illustrated in the drawing. Seal **61** is molded in steel cylinder **62**, which is held in place by a spring-clip or split washer at groove **63**. The entire device, including cylinder **62**, will slidably fit into a similarly shaped aperture wherein the top of cylinder **62** will abut or bottom against a wall. The seal is fabricated from materials of construction similar to those used in seal **60** of FIGURE 5A.

When the associated shaped charge of FIGURE 5B is fired, the terrific heat and pressure disintegrates insulator cylinder **159** to thereby permit the legs of the spring-loaded heat switch to spring apart, contacting the adjacent metal of the charge carrier, whereupon a ground to the next above charge carrier is provided thus arming the next above cap.

FIGURE 5C shows another modification of the heat velocity switch, in which the arming switch is provided with only one insulated leg **259**, which depends upon the conductivity of liquid to arm the device. Conductors **246** and **248** are portions of the two circuit legs of FIGURE 4. Numeral **64** indicates a resilient seal, preferably made of nylon, which is compressed by packing nut **65** into the steel block **23**, which block may be an integral part of the sub **12**, if desired.

As will be apparent from FIGURE 5C, the heat velocity switch at **259** is comprised of a single length of stainless steel or "piano wire," one end of which is attached to cap lead **247**, the other end of which is insulated as seen at **259**. Any suitable insulation may be used, as before, the only requirement being that at least a substantial portion be capable of being burned, melted, or blasted away by the explosion of the shaped charge so as to allow electrical contact with the fluid that will enter the charge carrier immediately after firing thereof. This liquid invariably contains sufficient impurities to permit conductivity between the metallic portions of the gun and the heat switch **259**, thus forming a ground for the electrical cap lead.

Gun operation

The perforating gun **10** is operatively assembled with multiple charge carriers **11** connected by subs **12**, each provided with a shaped charge **30**, jet outlet or aperture **33**, Primacord **37**, cap **41**, heat velocity switch **50**, and attendant wiring brought through seal **60** as required. The charge carrier of FIGURE 1 is in readiness to be fired assuming the next below heat velocity switch that is connected to conductor **57** has been properly triggered or activated, thus grounding conductor **57** to the metal of either the sub or the charge carrier wall as desired. Assuming the next below charge carrier of FIGURE 1 to have been detonated, the wires **46**, **48** will be fused or burned away into the next below seal **60** located in the sub **12** that connects the next below adjacent charge carrier (not shown). It should be understood that the wires **46**, **48** melt away in such a manner as to be fused up to and into the seal where they become effectively insulated

due to melting of the insulation about the copper wire, as should be apparent to one skilled in the art from this disclosure. Accordingly conductor **46** now is in open circuit condition, conductor **47** is in open circuit condition since the untriggered heat switch **50** shown above the shaped charge **30** is still insulated by its protective covering, and conductor **48** is now grounded through cap **41** through conductor **43** which leads to the triggered or activated heat switch connected to conductor **57**. An electrical charge imposed upon conductor **48** through one of the circuit legs will now detonate electrical cap **41**, which will explode Primacord **37** at **38**, which will accordingly ignite shaped charge **30** to provide a jet at aperture **33** thereby piercing the casing of a well.

The heat velocity switch **50**, being subjected to the intense release of energy by the shaped charge, Primacord, and cap, will now suffer immediate degradation of the protective coating thereon, allowing legs **51**, **52** to spring apart and contact the locking nut or metallic bushing **22**, thereby arming the next above adjacent charge carrier. The size of the spring steel or piano wire of the heat velocity switch must be selected so as to enable it to adsorb the heat and pressure levels caused by the charge without being distorted or destroyed.

A poorly chosen wire composition and size for the charge magnitude may result in a malfunction as indicated at **58** in FIGURE 3. In this case, however, both legs are seen to have contacted the lock nut **22** whereby direct grounding has been established. However, should the legs both fail to ground the nut **22**, the apparatus will still function, provided the protective coating **59** is disrupted, since the liquid surrounding the gun will fill the discharged charge carrier through the hole caused by the jet thereby allowing current flow through the conductive liquid to ground.

The firing operation continues in this manner until the desired number of charges have been detonated.

After now having read the foregoing portion of this specification, it should be within the comprehension of one skilled in the art to assemble an unlimited number of charge carriers into a jet perforating gun. It should be understood that this invention can also be practiced in conjunction with other wire line devices, including a perforating gun that fires projectiles.

Those skilled in the art may find other advantages, not necessarily limited to perforating guns, to flow from this disclosure; hence the following claims should be considered as defining that intellectual property to be protected by this Letters Patent.

I claim:

1. A perforating gun circuit having a power source and including; two diodes arranged in opposite polarity, each said diode having one end connected to a common terminal leading to a power source, with each of the other remaining ends connected to two parallel circuit legs, each circuit leg including series connected resistors, one of said legs having an electrically fired charge connected between one of said diodes and a first series resistor, and an electrically fired charge connected between each remaining series related resistors, the remaining said circuit leg having a multiplicity of series connected resistors, electrically fired charges each connected between each resistor in said second leg with the last charge being connected directly to ground, each charge in each leg being alternately arranged in individual charge carriers with the said grounded charge being the last charge of the series and the first charge to be detonated, and the first named charge in the first named leg being the last charge to be detonated, and switch means electrically connected to each said electrically fired charge to provide a return circuit path between the power source and the electrically fired charge upon the selective sequential firing of an adjacent charge carrier.

2. The circuitry of claim **1** in which the switch means is comprised of a metallic rod, one end of said rod including insulation means to rigidly affix the rod to the upper portion of one of said charge carriers and another end of said rod extending into the charge carrier, an insulating coating on said rod portion exposed to said charge carrier, whereby detonation of the charge carrier disrupts and degrades the insulation to thereby remove the insulation properties from said exposed portion of said rod, and render the rod an electrical conductor.

3. In a perforating gun having multiple charge carriers spaced apart from one another, means forming a passageway between adjacent charge carriers, and circuit means for sequentially firing said charge carrier, the improvement comprising: seal means removably fastened within said passageway said seal means comprising an electrically insulation means having the ability to withstand high temperatures and pressure, conductors sealed in and passing through said seal means, heat velocity switch means including a resilient metal rod bent about the center portion thereof to form an apex and sprung-apart legs, said switch apex being rigidly sealed inside said seal means, with each said leg depending freely therefrom, one of said conductors being electrically fastened to the apex of said switch, and heat degradable insulating means insulating said switch legs from adjacent structure.

4. The seal of claim **3** in which said seal is a tapered cylindrical plastic body rigidly enclosed in a similarly tapered steel body.

5. The seal of claim **3** in which the seal is enveloped in a cylinder which is rigidly and removably attached within the passageway by a clip located midway of the steel body.

6. The seal of claim **3** in which circuit components including a resistor is molded into the seal means.

7. In a perforating gun having multiple charge carriers, each connected by a body having a passageway therethrough, the improvement comprising:

a seal means in the passageway; said seal means comprising a cylindrical unitary molded body having electrical conductors sealed therein and extending into an adjacent charge carrier:

a heat switch including a wire bent into a configuration to define an apex and a depending leg; said apex being rigidly molded within said seal with said leg extending therefrom; means forming insulation about said leg; a conductor attached to said apex and extending from said seal in opposite relationship to said leg;

and a firing circuit means connected to said heat switch and adapted to fire each charge carrier in consecutive order in response to actuation of a heat switch located in one adjacent charge carrier.

8. The apparatus of claim **7** wherein: said circuit means includes a D.C. power source providing current to a common point connected to two circuit legs, one said circuit leg including a diode connected in series with multiple resistors, said multiple resistors each being in series with respect to each other, one conductor of an electrical two conductor explosive device connected between each resistor, said heat switch being normally open and connected between the remaining conductor of said electrical explosive device and return circuit to said source;

a second diode in the remaining said circuit leg having an opposite polarity with respect to the first said diode, multiple series resistors in series with respect to each other and to said second diode, a branch connection between each resistor to an electrical detonation means, means including another heat switch controlling current flow through said detonation means and adapted to close in response to the heat of reaction of another detonation means;

whereby, detonation of the charge furthest removed from the power source will sequentially arm the next adjacent charge by causing the heat switch

associated therewith to assume a conducting condition.

9. The apparatus of claim **8** in which said heat switch is comprised of a single length of resilient metal coated with heat sensitive insulation means.

10. The apparatus of claim **9** wherein said heat switch is bent about a point midway of its length to form two spring loaded legs, said insulation biasing said legs together; said legs, when subjected to heat are released from the insulation to thereby form a path for electrical current through parts of the said charge carrier.

11. In combination with a sealed perforating apparatus having separate chambers each containing electrically actuated explosive perforating means, with the apparatus having a bore interconnecting adjacent chambers, and electrical switching means for establishing a source of electrical current for each said explosive perforating means, the improvement comprising:

a molded non-conducting seal member of unitary construction affixed in the bore; a heat velocity switch, said switch comprising a length of wire bent about the center portion thereof to form two spaced apart legs and a center portion with each leg depending from said center portion and forming an included angle of less than 180° between each said leg; said center portion being rigidly molded within said seal member with a portion of each of said spaced apart legs depending from said seal member; and insulation means enclosing said depending legs;

an electrical conductor connected to said heat velocity switch within said seal member and extending from said seal member in opposite relationship to said depending legs;

said depending legs extending into one chamber containing electrically actuated explosive perforating means;

said electrical conductor extending into an adjacent chamber and electrically connected to the electrically actuated explosive perforating means to thereby form a path for current flow through said electrically actuated explosive perforating means when said heat velocity switch of an adjacent chamber is actuated;

circuit means including said electrical conductor adapted to complete an electrical circuit from said source of electrical current to the explosive perforating means in the one chamber, when the heat velocity switch in the adjacent chamber has been actuated;

second circuit means adapted to supply current from said source of electric current to the explosive perforating means in the next adjacent chamber;

whereby: activation of the electrical switching means detonates the explosive perforating means in the chamber containing said depending legs to thereby provide a path of current flow from the explosive perforating means associated with said second circuit means.

12. The apparatus of claim **11** wherein the electrical switching means is supplied with a D.C. power source providing current to a common point connected to two circuit legs, one said circuit leg comprising a diode electrically connected with multiple resistors, said multiple resistors each being in series with respect to each other, one conductor of an electrical two conductor explosive device connected between each resistor, said heat velocity switch having a normally open switch connected between the remaining conductor of said electrical explosive device and a return circuit to said source, the second said diode in the remaining said circuit leg having an opposite polarity with respect to the first said diode, multiple series resistors in series with said second diode, a branch connection between each resistor to an electrical detonation means, said switch means controlling current flow through said detonation means and responsive to the heat of reaction of said detonation means, whereby detonation of the charge furthest removed from the power source will sequentially arm the next adjacent charge.

13. The combination of claim **11** wherein said seal is enclosed in a metal cylinder, said cylinder having an annular groove about the outer peripheral surface thereof, and a clip adapted to removably attach said cylinder within the passageway.

14. The combination of claim **11** wherein said seal includes one of said resistors rigidly mounted in sealed relationship therein, and including circuit means connected thereto to enable said switch and resistor to be electrically connected to the explosive perforating means associated therewith.

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