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Eberline

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[54] **ELECTRICAL CABLE AND BOREHOLE LOGGING SYSTEM**

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[52] **U.S. Cl.** .... **166/54.5**, 102/21.2, 174/108, 174/113 R, 174/115, 340/18

[51] **Int. Cl.** **E21b 29/02**

[58] **Field of Search** .... 166/54.5, 54.6, 63; 324/7; 250/83.6; 340/18; 102/21.2; 174/108, 115, 113 R, 105, 107, 127 SC, 105 SC, 106 SC, 70 R, 70 S

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[57] **ABSTRACT**

Low-noise electrical cable includes a coaxial transmission line having a central conductor, a layer of insulation, and a tubular conductor sheathing the insulation, another layer of insulation sheathing the tubular conductor, a composite layer of insulated conductors and semiconductive material, two layers of semiconductive tape, and two layers of armor. In borehole radiation logging, the cable is connected to a downhole probe. Signals are transmitted to the surface along the central conductor, with the tubular conductor and armor grounded and power supplied to the probe through conductors in the composite layer. The probe includes exothermic material which is ignited to sever the cable from the probe should the probe become lodged in the borehole, for recovery of the cable.

11 Claims, 5 Drawing Figures

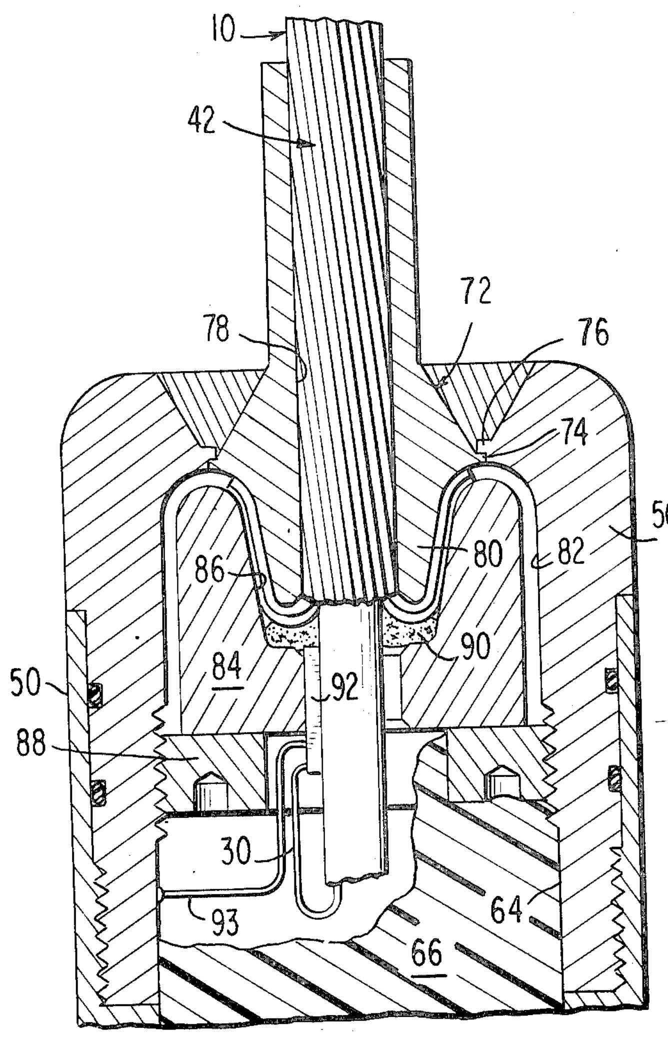

FIG.4

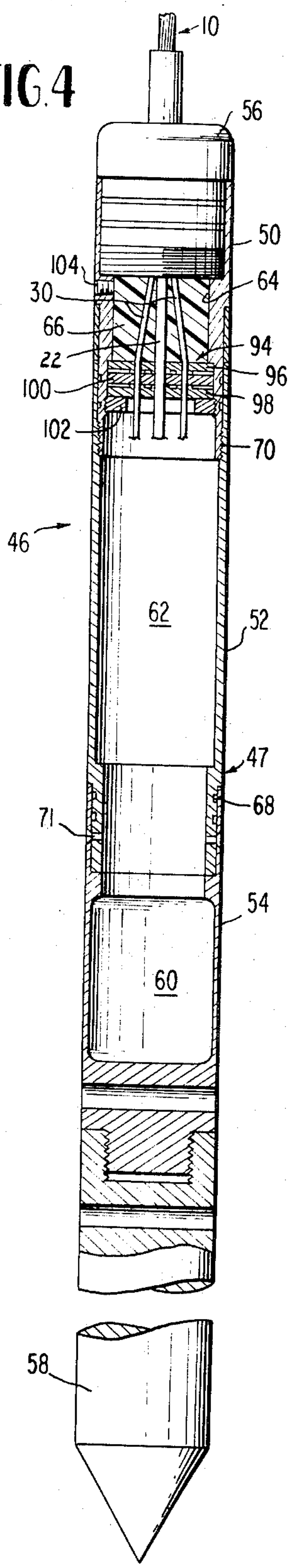

FIG.1

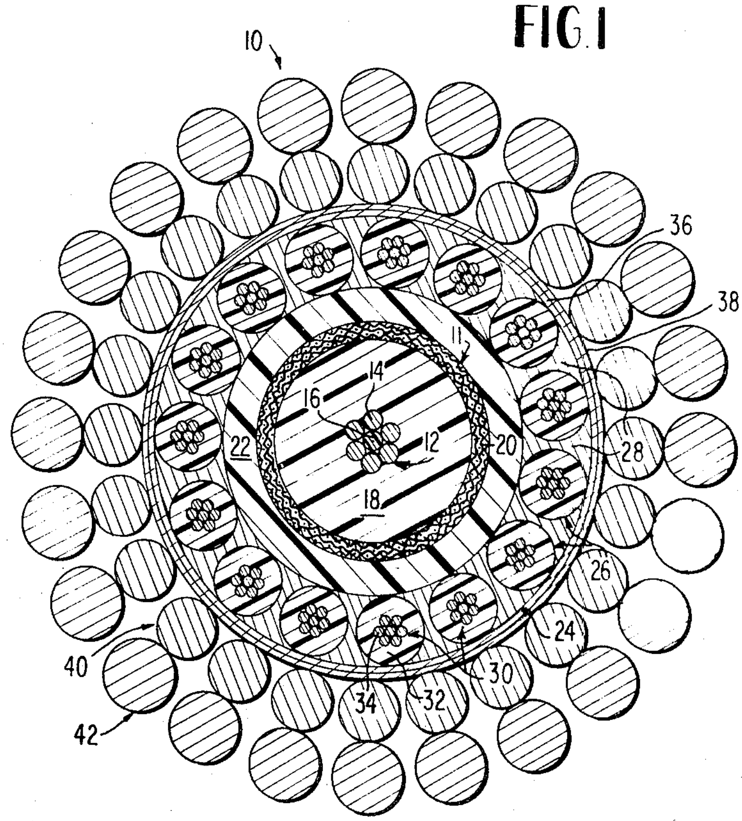

FIG.5

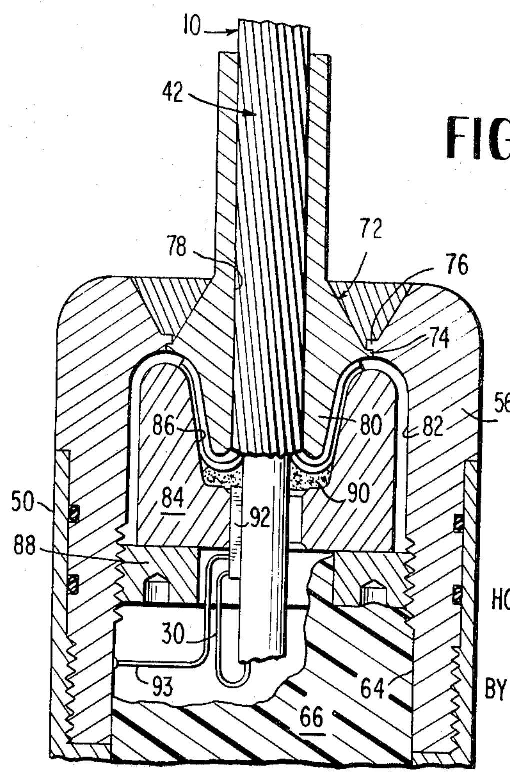

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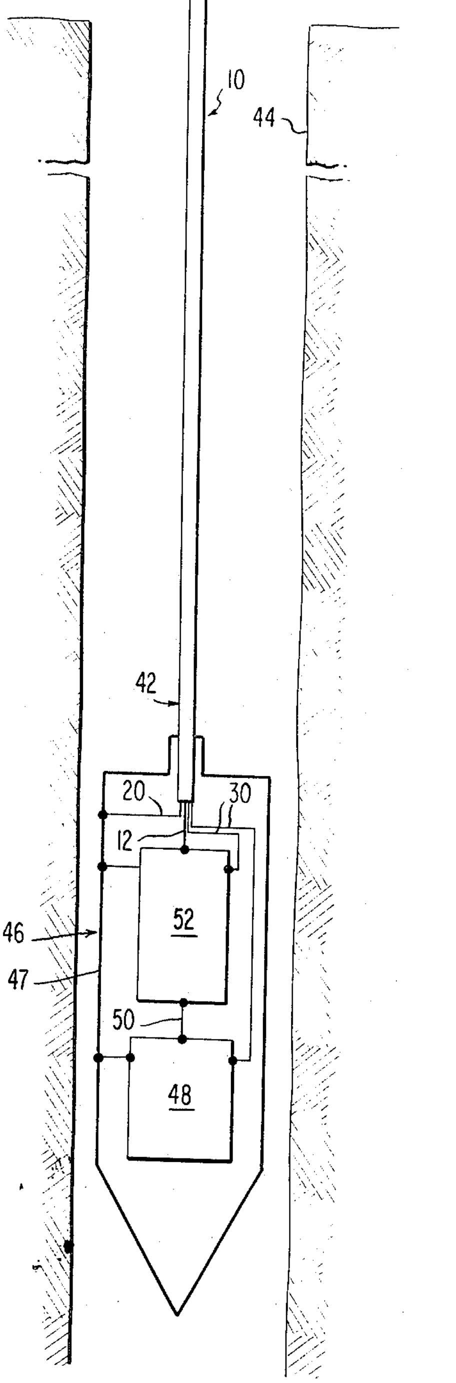
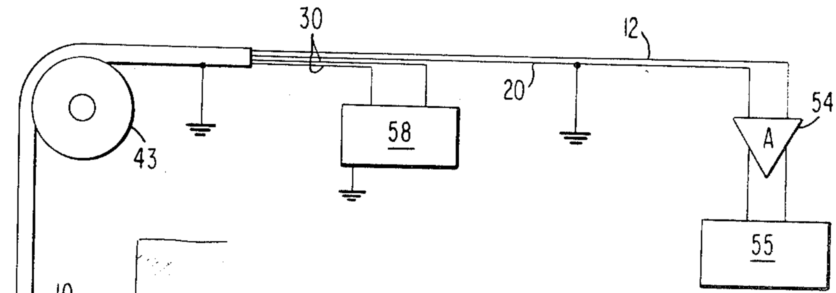
FIG 3

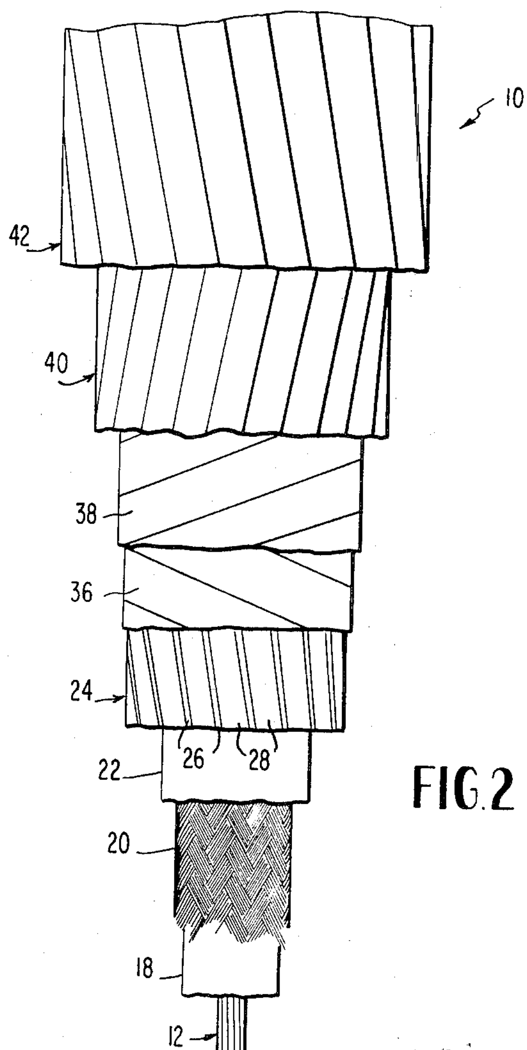


FIG 2

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ELECTRICAL CABLE AND BOREHOLE LOGGING SYSTEM

BACKGROUND OF THE INVENTION

Conventional borehold logging systems are unsatisfactory. There has been no cable having noise characteristics that are sufficiently low to avoid distorting or otherwise interfering with low-strength, high-frequency electrical signals transmitted by the cable from a downhole radiation detector to apparatus at the surface for analysis of the signals to produce useful information regarding earth formations traversed by the borehole. Hence, signal processing apparatus which could remain at the surface but for the noise has to be packed into the probe. This requires special design of apparatus to fit into the probe, and increases the size and cost of the probe.

In efforts to provide low-noise cables, various conductor arrangements have been proposed, together with semiconductive filler material and/or electrical shielding. However, such arrangements have not proved satisfactory for borehole radiation detection systems, because of the low strength of the signals and their sensitivity to distortion. Long-standing needs exist for improved, low-noise cables and borehole logging systems in which weak, high-frequency signals can be transmitted over thousands of feet of cable from a downhole probe to signal analyzing apparatus located at the surface of the earth. Main objects of the invention are fulfillment of these needs.

Another disadvantage of prior logging systems is lack of a satisfactory arrangement for separating the cable from the probe in the event that the probe became lodged in the borehole. Such an arrangement is highly desirable, for it not only permits recovery of the expensive cable, but also facilitates fishing for the probe because the cable is not present in the hole to interfere.

Another object of the invention is provision of borehole logging systems in which cable and probe are readily separable.

Other objects and advantages of the invention will appear from the following detailed description which, in connection with the accompanying drawings, discloses a preferred embodiment of the invention for purposes of illustration only and not for determination of the limits of the invention. For definition of the scope of the invention, reference will be made to the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, where similar reference characters denote similar elements throughout the several views:

FIG. 1 is a cross-sectional view of a cable embodying principles of the invention;

FIG. 2 is a side view of the cable of FIG. 1, with parts broken away;

FIG. 3 schematically illustrates a borehole logging system embodying principles of the invention;

FIG. 4 is a cross-sectional view of borehole logging apparatus embodying principles of the invention; and

FIG. 5 is an enlarged, detail view of the apparatus of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. 1 and 2 depict a cable 10 including a coaxial transmission line 11. Transmission line 11 includes a

central electrical conductor 12 including six helically wound copper wires 14. Wires 14 are wound around a nylon monofilament 16, and carry communications signals. A continuous flexible layer 18 of propylene copolymer electrical insulation sheaths central conductor 12.

A tubular conductor 20 of braided, tinned-copper wires sheaths insulation layer 18, forming the outer conductor of coaxial transmission line 11. Tubular conductor 20 is maintained in concentric relationship with central conductor 12 by the dielectric material of layer 18 which fills the annular cavity between the conductors. Another layer 22 of propylene copolymer electrical insulation sheaths braided tubular conductor 20, which is of circular cross-section.

A composite layer 24 sheaths insulation layer 22. Composite layer 24 is composed of a plurality of conductive members or insulated conductors 26, and masses 28 of semiconductive material interspersed between the conductive members. Conductive members 26 are disposed at spaced-apart locations around the outer periphery of insulation layer 22, completely encircling the insulation layer. Each conductive member 26 includes an electrical conductor 30 and a jacket 32 of propylene copolymer electrical insulation sheathing conductor 30. Each conductor 30 includes seven helically wound copper wires 34.

The conductive members are circular in cross section. Hence, opposed curved surfaces of adjacent insulation jackets 32, in receding from one another, define a peripheral row of generally V-shaped valleys adjacent insulation layer 22, and another peripheral row of generally V-shaped valleys at the outer periphery of composite layer 24. Since conductive members 26 are spaced from another, the valleys communicate with one another to form interstices or spaces extending radially through composite layer 24. The space between each pair of adjacent conductive members 26 is completely filled with a mass 28 of electrically semiconductive material, so that semiconductive material surrounds each conductive member 26 except at locations where the conductive member contacts insulating layer 22 and a layer 36, to be described, located radially outwardly of composite layer 24.

Each mass 28 of semiconductive material is in electrical contact with insulation layer 22, and with the jackets 32 of the conductive members on opposite sides of the mass. That is, the relationship of semiconductive material 28 to insulation layer 22 and to jackets 32 is such that electrostatic charges will pass from layer 22 and jackets 32 into the semiconductive material. As will appear, the semiconductive material conducts the charges to the conductive armor of the cable, for grounding. It will be appreciated that the necessary electrical relationship is established by physical contact between the elements, as illustrated, but is not destroyed by interposition of a semiconductive or conductive material. The semiconductive material of masses 28 is applied in a plastic state to fill the spaces between adjacent helically wound conductive members 26, and hardens in situ.

The semiconductive material can be of any suitable, conventional type, e.g., "Amertex," available in cables produced by United States Steel Corporation, Worchester, Massachusetts. Other semiconductive materials conventionally used in electrical cables can be employed, e.g., compounds of the polychloroprene rubbers.

A layer **36** of spirally wrapped, semiconductive tape, e.g., nylon tape impregnated with a semiconductive substance such as graphite, sheaths composite layer **24.** Tape layer **36** binds the assembly and aids in waterproofing the cable. The tape is in physical contact, and thus in electrical contact, with each mass of semiconductive material in composite layer **24.** Another, oppositely wound, layer **38** of identical semiconductive tape sheaths inner tape layer **36,** and is in physical and therefore electrical contact with the tape of layer **36.** The outer tape layer **38** assures adequate waterproofing.

The assembly thus far described is sheathed by two layers **40, 42** of galvanized steel armor wires, which protect the internal elements of the cable from physical damage. The armor layers are in electrical contact with the semiconductive material of composite layer **24** through the semiconductive tape layers **36, 38.** The inner layer **40** of armor is in physical contact with tape layer **38,** and is wound with a right hand lay. Outer layer **42** of armor is in physical contact with inner layer **40,** and is wound with a left hand lay.

Cables made in accordance with the invention are highly advantageous in having remarkable low noise characteristics. Use of a coaxial transmission line makes for low loss transmission of weak high-frequency signals. Electrostatic charges generated by sliding of cable components over one another during cable flexure, which charges would otherwise build up and then discharge and thus generate noise voltages and adversely affect communications signals, are continuously drained by the semiconductive material and carried to the conductive armor for grounding. The outer conductor **20** of the coaxial transmission line is grounded and therefore further contributes to noise reduction by shielding or isolating the central communications conductor **12** from external signals which could interfere with signal transmission along conductor **12.**

Cable **10** is shown in use in the borehole logging system schematically represented in FIG. **3.** In this system, cable **10** extends from the surface of the earth over a supporting sheave **43** into a borehole **44.** A probe **46** is connected to cable **10** and includes a gamma radiation detector **48,** which can be of any suitable type of conventional design. Detector **48** detects radiation emanating from adjacent earth strata and produces an electrical signal corresponding to the detected radiation. This signal is too weak to reach the surface of the earth and is therefore transmitted by conductor **50** to a preamplifier **52** for preamplification to a strength level (e.g., with a gain of 10) sufficient to carry to the surface. The preamplified radiofrequency signal is transmitted directly, without further amplification, to central conductor **12** for transmission along cable **10.** The signal is carried by cable **10** to amplifier **54** and signal analyzing apparatus **55,** which are located at the surface of the earth. Signal analyzing apparatus **55** can be of any suitable, conventional type for analyzing the signals and translating them into useful intelligence regarding earth strata traversed by the borehole.

Electrical power for energizing preamplifier **52** and detector **48** is supplied to probe **46** from a power supply and control unit **58** at the surface of the earth through two of the conductors **30,** respectively. Other conductors **30** can be used to energize other measuring instruments (not shown) contained in the probe. Tubular conductor **20** is at ground potential and functions as a return for power unit **58** by virtue of electrical connection to metallic probe casing **47,** to which the energizing and radiofrequency circuits of detector **48** and preamplifier **52** are electrically connected. The cable armor is electrically grounded through drilling fluid or other liquid in the borehole and through an electrical ground connection at the surface, so that electrostatic charges received from the interior of the cable are drained to earth to prevent their causing noise in the cable.

Borehole logging systems according to the invention are particularly advantageous. Because of the low-noise cable, the accuracy and speed of logging can be increased. Without distortion of the communication signals, accurate interpretation can be effected. Logging systems according to the invention have been operated without noise at cable speeds of 250 feet per minute with input sensitivities as low as 1 millivolt, which is unprecedented. Further, the amount of electronic gear present in the probe can be minimized, so that need for specially designed apparatus to fit into the probe is reduced to a minimum and a compact and inexpensive probe is provided.

As shown in FIG. **4,** hollow, cylindrical metal casing **47** of probe **46** includes three separable cylinders **50, 52, 54,** and a cap **56.** A weight **58** is screwed to lower cylinder **54,** which includes a cavity **60** for receiving the radiation detector. Intermediate cylinder **52** includes a cavity **62** for receiving the preamplifier. Upper cylinder **50** includes a cavity **64** in which the conductive components of the cable are separated, and which is filled with a mass **66** of silicone sealing material for waterproofing the probe.

The cylinders separate from one another to facilitate access to the instruments and other elements within the probe. Resilient O-rings such as **68** form tight seals when the cylinders are assembled. Cylinders **50, 52** are joined by mating threads **70** on their respective outer and inner peripheries. The lower end of cylinder **52** slip-fits into cylinder **54,** with radial screws **71** interconnecting the cylinders.

Cap **56** includes a central orifice which receives a metal sleeve **72** (FIG. **5**). Sleeve **72** has a circular shoulder **74** bearing against a circular shoulder **76** on cap **56.** A central aperture **78** in sleeve **72** receives the end portion of cable **10.** The sleeve includes a generally frustoconical portion **80** which projects into cavity **82** in cap **56.** Aperture **78** extends axially through projecting portion **80.** The two layers of armor are peeled away from the remainder of the cable, and the tips of alternate armor wires in each layer cut off. The remaining tips are deformed backwardly over the outer surfaces of projecting portion **80** at an angle of nearly 180°. A cup-shaped lock member **84,** having a central recess **86** which receives the deformed armor and projecting portion **80,** is shaped to press the deformed armor against the outer surfaces of projecting portion **80** to secure the cable to the probe. Rotation of a nut **88** threadedly engaging the inner periphery of cap **56** forces lock **84** into locking position, deforming the armor securely against projecting portion **80.** Nut **88** secures lock **84** in position so that the armor bears the load of the probe. Lock **84** and nut **88** include central apertures for the conductive portion of cable **10** to proceed axially into the probe.

Within the top end portion of the probe, between lock 84 and the inner end of projecting portion 80, and packed against the deformed armor, is a cable severing means such as a mass 90 of exothermic material. The exothermic material may be a conventional Thermit mixture of iron oxide and aluminum, an explosive charge or the like. This mass of exothermic material surrounds the end portion of the cable, and on ignition sever sever all segments of the cable in the immediate vicinity, including the deformed armor sections which connect the cable to the probe, thereby severing the cable from the probe. When the exothermic material is a Thermit mixture, it may be ignited by application of electric current to an electrical resistance heater 92 which is in heat exchange relationship with mass 90 of exothermic material by virtue of physical contact therewith. Current is supplied to resistor 92 from the surface power source through one of the conductors 30 with the circuit being completed by a connection 93 to the probe casing. Whenever probe 46 becomes stuck in borehole 44, the exothermic material is ignited by closure of a switch in the circuit to resistor 92 and the destruction of the cable at this point separates the probe from the main body of the cable so that the cable can be recovered from the borehole. The cable is thereby recovered, while clearing the borehole for fishing for the probe should this be desired.

Conductive components of cable 10 diverge in cavity 64 (FIG. 4), with conductors 30 passing through a circular row of apertures in a sealing gland assembly 94. The coaxial transmission line, within insulating sheath 22, passes through a central aperture in assembly 94.

Gland assembly 94 includes upper and lower compression plates 96, 98, between which is interposed a compression gland 100. Rotation of a nut 102 threadedly engaging the interior surfaces of upper cylinder 50 compresses the gland between the plates to form a tight seal around the conductors which pass axially into the probe for appropriate electrical connection. Mass 66 of sealing compound is injected in a plastic state under pressure through an aperture in a side wall of cylinder 50 and hardens in place to effectively waterproof the probe. The aperture has threaded sidewalls which engage a screw plug 104 inserted in the aperture after injection of the sealing material.

Over a period of approximately 26 months, a series of tests was conducted to determine the reliability of the signals obtained utilizing the apparatus of the instant invention. During this interval, test holes were drilled in varying types of formations in several states. The signals received at the surface from the probe were analyzed and compared with core samples obtained from the holes. During the course of these tests various changes and modifications were made. The results of these tests have established that with the apparatus of the instant invention it now is possible to obtain substantially noise free signals from the probe, even when it is being lowered into the hole at a high rate of speed, which signals accurately report the mineral structure at various levels in the hole.

Although the invention has been described in connection with a preferred embodiment, modifications of that embodiment can be made without departing from the principles of the invention. Such modifications and variations are within the scope of the appended claims.

I claim:

1. Borehole logging apparatus, comprising
a cable having a probe end portion,
a probe connected to the probe end portion of the cable,
means including a mass of exothermic mixture of iron oxide and aluminum operatively associated with the probe end portion of the cable for severing the cable from the probe, and
igniting means for igniting the exothermic mixture.

2. The apparatus of claim 1,
the igniting means including an electrical resistance heater in heat exchange relationship with the mass of exothermic mixture.

3. The apparatus of claim 1,
the probe including an end portion having an aperture for receiving a portion of the cable,
the mass of exothermic mixture being located within the end portion of the probe and contiguous to the received portion of the cable.

4. The apparatus of claim 3,
the cable including at least one layer of armor,
the end portion of the probe including a cavity and a projecting member extending into the cavity and having outer surfaces,
the aperture extending through the projecting member,
at least a portion of the armor being peeled away from the remainder of the cable and deformed backwardly over the outer surfaces of the projecting member, and
the probe including locking means pressing the deformed armor against the outer surfaces of the projecting member for locking the cable to the probe.

5. The apparatus of claim 4,
the mass of exothermic mixture being located between the locking means and the projecting member in a position to sever the deformed armor.

6. The apparatus of claim 4,
the locking means including
a locking member having a central recess receiving the deformed armor and the projecting member, and
movable means for forcing the locking member into locking position.

7. Borehole logging apparatus, comprising
a cable having a probe end portion,
a probe connected to the probe end portion of the cable,
means including a mass of exothermic material operatively associated with the probe end portion of the cable for severing the cable from the probe, and
igniting means for igniting the exothermic material,
the probe receiving a portion of the cable,
the mass of exothermic material being located within the probe and contiguous to the received portion of the cable,
the cable including at least one layer of armor,
the probe including means including surfaces defining a cavity in the probe,
the end portion of the cable extending into the cavity,
at least a portion of the armor being peeled away from the remainder of the cable and deformed over said surfaces,
the probe including locking means pressing the deformed armor against said surfaces for locking the cable to the probe.

8. The apparatus of claim 7,

the mass of exothermic material being located between the locking means and said surfaces in a position to sever the deformed armor.

9. The apparatus of claim **7,**

the probe including a projecting member extending into the cavity,

the cable extending through the projecting member,

said surfaces including outer surfaces of the projecting member,

the deformed armor being deformed backwardly at an angle of nearly 180° over the outer surfaces of the projecting member.

10. The apparatus of claim **9,**

the mass of exothermic material being located between the locking means and said surfaces in a position to sever the deformed armor.

11. The apparatus of claim **9,**

the locking means including a locking member having a central recess receiving the deformed armor and the projecting member, and

movable means for forcing the locking member into locking position.

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