

(19)



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11)

EP 0 412 576 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:
28.08.1996 Bulletin 1996/35

(51) Int Cl.⁶: **F02P 9/00, H01T 13/40**

(21) Application number: **90117485.4**

(22) Date of filing: **26.02.1985**

(54) Apparatus for igniting the combustion of a fuel-air mixture

Vorrichtung zum Zünden der Verbrennung eines Kraftstoff-Luftgemisches

Dispositif d'allumage de la combustion d'un mélange d'air et de carburant

(84) Designated Contracting States:
AT BE CH DE FR LI

(30) Priority: **27.02.1984 US 583694**
14.02.1985 US 701482

(43) Date of publication of application:
13.02.1991 Bulletin 1991/07

(62) Application number of earlier application in
accordance with Art. 76 EPC: **85901280.9**

(73) Proprietor: **Hensley Plasma Plug Partnership**
dba HDI Research
Albuquerque, New Mexico 87109 (US)

(72) Inventors:

- **Pate, Roland C.**
Albuquerque, New Mexico 87114 (US)
- **Hensley, Raymond E.**
Albuquerque, New Mexico 87111 (US)

(74) Representative: **Schaumburg, Thoenes & Thurn**
Mauerkircherstrasse 31
81679 München (DE)

(56) References cited:

BE-A- 573 091 **DE-A- 2 363 804**
DE-A- 2 400 623 **FR-A- 2 317 804**
US-A- 4 324 219

- **PATENT ABSTRACTS OF JAPAN, vol. 4, no. 37**
(M-4)[519], 27th March 1980; & JP-A-55 10 050

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 0 412 576 B1

Description

This invention relates to an apparatus for initiating combustion of fuel-air mixtures in an internal combustion engine, as defined in the preamble of claim 1.

An apparatus of this kind is known from US-A-4,333,125. Furthermore, it is referred to Combustion and Flame 27, published 1976, R. Knystautas and J.H. Lee, on the Effective Energy for Direct Initiation of Gaseous Detonations, pages 221-228. The known apparatus includes a capacitive portion for storing a large quantity of electrical energy therein derived from a power supply, and an electrode portion integral with the capacitive portion which comprises a pair of concentric, rod shaped electrodes for producing a high energy, umbrella shaped plasma discharge, using the inverse pinch technique. Due to the close proximity between the capacitive and electrode portions of the initiating device, rapid energy transfer from the former to the latter creates high magnetic pressures which transform the discharge into a high energy plasma jet which is delivered well into the combustion area.

According to this principle, despite the fact that the ignition can be enhanced, the power coupling efficiency from a relatively high impedance ignition source circuit to the very low impedance of an established discharge channel is quite low, resulting in a greater fraction of the available energy being lost through power dissipation in circuit resistance other than the discharge channel itself. Somewhat greater power dissipation in the discharge channel can be achieved by increasing the magnitude of current flow. However, for a given discharge duration, this may be accomplished only at the expense of greater energy input requirements and severe electrode wear.

Accordingly, it is the problem to be solved by this invention to create an apparatus for igniting combustion of fuel-air mixtures, which generates a very rapid intense high power electric breakdown.

The invention solves this problem by an apparatus having the features of claim 1. Further developments of this apparatus are described in the subclaims.

The ignition apparatus of the present invention employs a hard-discharge-ignition (HDI) process which is generated by a very rapid, intense, high-power electrical breakdown which we shall refer to as a "hard" spark discharge. HDI initiation of combustion employs highly effective energy coupling mechanisms which reach high levels of intensity. The term "hard-discharge" as used herein refers to the regime of operation in which the discharge circuit inductance and resistance are sufficiently low that the rate of current flow and rate of energy deposition in the discharge channel during the breakdown phase are largely governed by the resistance of the spark channel itself.

This extreme regime of operation is characterized by highly efficient coupling (80-95%) of the initially stored electrical circuit energy, during approximately the first half-period of the discharge current cycle, into the

various transient processes associated with gaseous discharge formation and expansion. As a result, hard-discharge operation delivers most of the available pulse energy within the breakdown phase of the discharge (usually within the first few tens of nanoseconds of the discharge), thereby achieving maximum power-coupling from the driving circuit to the rapidly dropping effective load impedance of the discharge channel. Using typical discharge circuit energy levels of between 0.05 to 2 joules, and with rates of rise of breakdown current flow on the order of 10^{10} to 10^{12} amperes per second, the resulting power deposition can approach an order of 10^9 to 10^{10} watts within the time span of a few 10^{-8} to 10^{-7} seconds.

Additionally, the greatly enhanced speed of the overall combustion event significantly reduces the amount of ignition timing advance necessary for MBT (maximum brake torque) operation with a given fuel-air mixture. Depending upon the mixture ratio, engine conditions, and HDI energy and power level, the need for timing advance may be entirely eliminated. Consequently, highly efficient engine operation is provided with significantly reduced ignition timing advance.

In the drawings, which form an integral part of the specification and are to be read in conjunction therewith, and in which like reference numerals are employed to designate identical components in the various views:

FIGURE 1 is a schematic diagram of an equivalent electrical circuit for generating a hard discharge ignition in accordance with the present invention;

FIGURE 2 is a longitudinal sectional view of a distribution cable employing a pulse forming network (PFN) having lumped capacitance;

FIGURE 3 is a perspective view, parts being broken away in section, of another distribution cable having a pulse forming network employing lumped capacitance;

FIGURES 4A and 4B are longitudinal, sectional views of portions of distribution cables employing a pulse forming network having distributed capacitance;

FIGURE 5 is a cross-sectional view of a termination connector for use with the distribution cable shown in FIGURE 4A;

The rate of admission of energy into the breakdown channel in a spark gap must be maximized in order to achieve high power coupling efficiency and to maximize the intensity of the energy transfer mechanisms which are important in accordance with the present invention for ignition applications. This may be accomplished by using a very low inductance, low impedance, capacitive-discharge or driving circuit represented by the simplified

equivalent model shown in FIGURE 1. As used in this description, the term "driving circuit" refers to all of the high voltage discharge circuit components, connecting conductors, and structures other than the breakdown gap and gaseous discharge path itself. Capacitor C represents the total effective discharge circuit capacitance, inductor L_o represents the total effective discharge circuit inductance, and resistance R_o represents the total effective discharge circuit resistance. The reactive term component of the characteristic impedance of the discharge circuit is expressed as:

$$Z = \sqrt{L_o/C}$$

C may be a discrete, lumped-element capacitor connected to the spark gap by means of a low inductance lead configuration, or it can be a distributed capacitance in the form of a very low-impedance, low-inductance waveguide structure which acts as a distributed pulse-forming-network (PFN). With operating voltages typically in the range of 20 to 40 kv, the magnitude of the capacitor C will fall within the range of approximately 100 picofarads to about 5 nanofarads. L_o includes the inductance of all connecting conductors and the inductance associated with the discrete or distributed capacitive unit and must generally be on the order of a few hundred nanohenries or less. R_o includes the resistance of the circuit conductors as well as the effective resistive loss associated with dielectric losses in the capacitive element. In practice, R_o should be no more than a few ohms, and preferably should be minimized to the sub-ohm level. In general, this approach toward ignition system operation contrasts with the prior art approach which lays heavy emphasis upon higher impedance, higher inductance, lower capacitance driving circuitry and considerably longer discharge duration at lower intensities.

The equivalent lumped circuit model components for the spark gap are indicated by dashed lines in FIGURE 1. C_g is the capacitance of the gap prior to breakdown and is typically on the order of 10 picofarads (10pf). C_g is important for storing the charge needed during the very early stages of the breakdown channel formation, but the magnitude of C_g is small compared to C and can be neglected once the early breakdown channel has been established. Closing of switch S_b represents the onset of the breakdown event in which an ionized current flow path is formed between the spark gap electrodes.

The detailed mechanisms involved in this process depend upon the conditions of the gas in the gap and the manner in which the voltage is applied. For purposes of this disclosure, it may be assumed that the establishment of current flow across the gap may be represented by the closing of the switch S_b . C_g is then effectively shunted by the time-varying channel inductance $L_g(t)$ and resistance $R_g(t)$. The circuit operation begins after capacitor C is charged to an initial voltage V_o .

For ignition applications of HDI, maximum perform-

ance is obtained using voltages from 20 kV to 40 kV, and a discharge circuit capacitance of 100 picofarads to several nanofarads, values of L/l_g on the order of a few hundred nanohenries of discharge circuit inductance (L) per centimeter of discharge gap length (l_g), or less, preferably equal to or less than 80 nanohenries per centimeter, depending on the value of capacitance C and the effective working gap breakdown electric field E_o .

As a practical matter, reducing the overall circuit inductance to values of L/l_g below approximately 10 nH/cm is quite difficult in high voltage discharge circuits where certain minimum physical spacing is required for electrical insulation. In fact, the breakdown channel itself typically has self-inductance on the order of 10nH/cm. In cases where insufficient hardness has been achieved despite the minimization of L/l_g to practical limits, the major alternative for increasing hardness are to decrease the capacitance C and/or to effectively increase E_o by overvolting the discharge gap. Investigations with hard open air discharges have shown that for values of C less than or approximately equal to 3 nanofarads, an increase in energy caused by increasing the working voltage V_o and gap length l_g yields a shorter discharge current duration and a longer duration of light output with light output in very hard discharges continuing well beyond the cessation of current flow (afterglow).

Reference is now made to FIGURE 2 wherein a discrete capacitance PFN is disclosed. The PFN, generally indicated at 122 is formed in a coaxial cable 123 which connects a power supply (not shown) with a connector (not shown) which is adapted to connect the cable 123 with an ignitor.

The PFN 122 comprises an inner conductor 130 surrounded by a sleeve 136 of high dielectric material, such as ceramic. A layer 134 of metalization on the outer surface of the dielectric sleeve 136 is connected with the outer conductor 127 and thus forms a continuous path for the flow of current through the cable 123. The inner conductor 130 is of substantially larger diameter than the central conductor 128 of the cable 123 and is connected at its ends to the central conductor 128 as by welding or the like. A layer of dielectric potting compound 132 surrounds the connection between the central conductor 128 and inner conductor 130. Inner conductor 130 in combination with the dielectric sleeve 136 and metalization 134 forms a capacitor which is in close proximity to the ignitor 52.

Although the PFN 122 provides a discharge circuit of high impedance and inductance, it possesses the advantage of providing an ignitor which is relatively small and eliminates the problem of deleterious effects on the capacitor by additional heat to which it is subjected if positioned contiguous to the combustion chamber.

Another form of discrete capacitance PFN is depicted in Figure 3. The PFN 144 is connected in series with the coaxial power supply cable 146 which connects the power supply (not shown) with a coaxial ignitor 52. The

PFN 144 comprises first and second sets of flat plate capacitors 152, 154 which are interleaved and spaced apart using a dielectric material 156 to form a series of capacitor plates. Plates 12 are connected with the outer conductor of cable 146 while capacitor plates 154 are connected with its central conductor 148.

A distributed capacitance PFN 158 is depicted in FIGURE 4A, which is formed integral with the distribution cable connecting the ignitor with the high voltage power supply. The cable including the PFN 158 is substantially flexible but yet does not possess a diameter too large to be used in existing automobile engines. The PFN 158 comprises a stripline geometry in which a plurality of flexible, outer foil conductors 160 are interleaved with a plurality of inner foil conductors 164 and are separated therefrom by a plurality of layers 162 of dielectric material such as a polyamide film. The foil conductors 160, 164 may extend a substantial portion of the length of the entire cable and the sandwiched construction is enclosed by an outer rubber or plastic jacket 166.

As shown in FIGURE 5, the stripline configuration may be terminated in a connector 168 which is adapted to releasably connect the cable with an ignitor. The inner foil conductors 164 are terminated in a single connection which is secured to a center conductor 172 which in turn is connected with a metal contact 174 disposed within a cap 176 which fits over the terminal end of the ignitor. The foil conductors 160 are terminated in a connection with lead lines 170 within the cap 176. Contacts 174 and lead lines 170 respectively interconnect with the electrodes of the ignitor.

Another form of distributed capacitance PFN is depicted in FIGURE 4B. The PFN comprises a coaxial cable 123 which is connected to an ignitor (not shown) by a connector 138. The connector 138 includes an outer threaded coupling 142 which is threadably received by a portion of the ignitor, and an inner electrical connecting portion 140 which electrically connects the electrodes of the ignitor with the central conductor 128 and outer conductor 127 of the cable 123. The inner and outer conductors 127 and 128 form the distributed capacitance.

Claims

1. Apparatus for igniting the combustion of a fuel-air mixture in a spark gap of an ignitor in an internal combustion engine, comprising an electrical discharge circuit including a capacitor (122, 144, 158) for storing a quantity of electrical energy, and a pair of electrical conductors for electrically connecting said capacitor (122, 144, 158) with said ignitor (52), said capacitor (122, 158, 144) being inserted and/or distributed along at least a portion of an electrical distribution cable (123, 146, 180) for connecting said capacitor (122, 144, 158) with a high voltage source, **characterized** in that the capacitor has a capacitance of 100 to 5000 pF, whereas the

ratio of the inductance of said discharge circuit including the capacitor (122, 144, 158) to the length of said spark gap is less than approximately 80 nanohenries per centimeter.

2. The apparatus of claim 1, **characterized** in that said distribution cable is a coaxial cable (123) the inner conductor (130) of which has an increased diameter on a certain length and is surrounded by a sleeve (136) of high dielectric material having an outer metallization layer (134) which is connected with the outer conductor (127) of said coaxial cable (123), the portion of increased diameter being connected at its ends with the inner conductor (128) of small diameter, the connection being surrounded by a layer (132) of dielectric potting compound.
3. The apparatus of claim 1, **characterized** in that said distribution cable is a coaxial cable (146, 180) whose outer and inner conductor (148) is connected in series with first and second sets of flat interleaved and spaced apart capacitor plates (152, 154), respectively.
4. The apparatus of claim 3, **characterized** by a stripline capacitor (158) formed integral with said coaxial distribution cable (180) in which a plurality of outer foil conductors (160) forming said first capacitor plates are interleaved with a plurality of inner foil conductors (164) forming said second capacitor plates and are separated therefrom by a plurality of layers (162) of dielectric material.
5. The apparatus of claim 4, **characterized** in that the stripline capacitor (158) terminates in a connector (168) for the connection with an ignitor, said inner foil conductors (164) terminating in a single connection with a center conductor (172) within a cap (176) of said connector (168), and said outer conductors (160) terminating in a connection with lead lines (170) within said cap (176), said center conductor (172) and said lead lines (170) being connectable with the electrodes of said ignitor.

6. The apparatus of claim 1, **characterized** in that said capacitor is formed by an inner and an outer conductor (127, 128) of a coaxial distribution cable (123) which terminates in a connector (138) having an electrical connecting portion (140) for connecting the electrodes of the ignitor with the conductors (127, 128) of said coaxial distribution cable (123).

Patentansprüche

1. Vorrichtung zum Zünden der Verbrennung eines Kraftstoff-Luftgemisches in der Funkenstrecke einer Zündkerze in einer Brennkraftmaschine, mit ei-

nem elektrischen Entladestromkreis mit einem Kondensator (122, 144, 158) zum Speichern einer Menge elektrischer Energie und mit einem Paar elektrischer Leiter zum elektrischen Verbinden des Kondensators (122, 144, 158) mit der Zündkerze (52), wobei der Kondensator (122, 144, 158) in mindestens einen Teil eines elektrischen Verteilerkabels (123, 146, 180) zum Verbinden des Kondensators (122, 144, 158) mit einer Hochspannungsquelle eingesetzt und/oder darüber verteilt ist, dadurch **gekennzeichnet**, daß der Kondensator eine Kapazität von 100 bis 5000 Picofarad hat, während das Verhältnis der Induktivität des Entladestromkreises einschließlich Kondensator (122, 144, 158) zu der Länge der Funkenstrecke kleiner als etwa 80 Nanohenry pro cm ist.

2. Vorrichtung nach Anspruch 1, dadurch **gekennzeichnet**, daß das Verteilerkabel ein Koaxialkabel (123) ist, dessen Innenleiter (130) über eine gewisse Länge einen vergrößerten Durchmesser hat und von einer Hülse (136) aus einem Material hoher Dielektrizität mit einer äußeren Metallisierungsschicht (134) umgeben ist, die mit dem Außenleiter (127) des Koaxialkabels (123) verbunden ist, wobei der Teil vergrößerten Durchmessers an seinen Enden mit dem Innenleiter (128) kleinen Durchmessers verbunden ist und diese Verbindung von einer Schicht (132) aus dielektrischem Vergußmaterial umgeben ist.

3. Vorrichtung nach Anspruch 1, dadurch **gekennzeichnet**, daß das Verteilerkabel ein Koaxialkabel (146, 180) ist, dessen Außen- und Innenleiter (148) mit einer ersten bzw. einer zweiten Gruppe flacher und mit gegenseitigem Abstand ineinander verschachtelter Kondensatorplatten (152, 154) in Reihe geschaltet ist.

4. Vorrichtung nach Anspruch 3, **gekennzeichnet** durch einen Streifenleiter-Kondensator (158), der integral mit dem koaxialen Verteilerkabel (180) ausgebildet ist und in dem mehrere äußere Folienleiter (160) erste Kondensatorplatten bilden und mit mehreren inneren Folienleitern (164) als zweite Kondensatorplatten verschachtelt und von diesen durch mehrere Schichten (162) aus dielektrischem Material getrennt sind.

5. Vorrichtung nach Anspruch 4, dadurch **gekennzeichnet**, daß der Streifenleiter-Kondensator (158) in einem Verbinder (168) zur Verbindung mit einer Zündkerze endet, daß die inneren Folienleiter (164) in einer einzelnen Verbindung mit einem zentralen Leiter (172) innerhalb einer Kappe (176) des Verbinders (168) enden, und daß die Außenleiter (160) in einer Verbindung mit Leitungen (170) innerhalb der Kappe (176) enden, wobei der zentrale Leiter

(172) und die Leitungen (170) mit den Elektroden der Zündkerze verbindbar sind.

6. Vorrichtung nach Anspruch 1, dadurch **gekennzeichnet**, daß der Kondensator aus einem inneren und einem äußeren Leiter (127, 128) eines koaxialen Verteilerkabels (123) gebildet ist, das in einem Verbinder (138) mit einem elektrischen Verbindungsteil (140) zum Verbinden der Elektroden der Zündkerze mit den Leitern (127, 128) des koaxialen Verteilerkabels (123) endet.

Revendications

1. Appareil pour allumer la combustion d'un mélange carburant/air dans un espace de décharge par étincelles d'un dispositif d'allumage dans un moteur à combustion interne, comprenant un circuit de décharge électrique incluant un condensateur (122, 144, 158) pour accumuler une certaine quantité d'énergie électrique, et une paire de conducteurs électriques pour connecter électriquement ledit condensateur (122, 144, 158) audit dispositif d'allumage (52), ledit condensateur (122, 144, 158) étant inséré et/ou distribué le long d'au moins une partie d'un câble de distribution électrique (123, 146, 180) pour connecter ledit condensateur (122, 144, 158) à une source haute tension, caractérisé en ce que le condensateur a une capacité située entre 100 à 5000 picofarads, tandis que le rapport de l'inductance dudit circuit de décharge comportant le condensateur (122, 144, 158) à la longueur dudit espace de décharge par étincelles est approximativement inférieur à 80 nanohenrys par centimètre.

2. Appareil selon la revendication 1, caractérisé en ce que le câble de distribution est un câble coaxial (123), dont le conducteur interne (130) présente un diamètre accru sur une certaine longueur et est entouré par un manchon (136) constitué d'un matériau hautement diélectrique ayant une couche de métallisation extérieure (134) qui est connectée au conducteur extérieur (127) dudit câble coaxial (123), la partie de diamètre accru étant connectée à ses extrémités au conducteur interne (128) de diamètre faible, la connexion étant entourée par une couche (132) d'un composé d'enrobage diélectrique.

3. Appareil selon la revendication 1, caractérisé en ce que le câble de distribution est un câble coaxial (146, 180) dont le conducteur extérieur et le conducteur intérieur (146, 148) sont connectés en série respectivement à des premier et second ensembles de plaques plates (152, 154) de condensateur qui sont intercalées entre elles sans contact.

4. Appareil selon la revendication 3, caractérisé par

un condensateur à ligne multiplaque (158) formé de manière solidaire avec le câble de distribution coaxial (180), dans lequel une pluralité de conducteurs en feuilles externes (160) formant lesdites premières plaques de condensateur sont intercalées avec une pluralité de conducteurs en feuilles internes (164) formant lesdites secondes plaques de condensateur et sont séparées de celles-ci par une pluralité de couches (162) d'un matériau diélectrique.

5

10

5. Appareil selon la revendication 4, caractérisé en ce que le condensateur à ligne multiplaque (158) se termine en un connecteur (168) pour la connexion à un dispositif d'allumage, lesdits conducteurs en feuilles internes (164) se terminant en une seule connexion avec un conducteur central (172) à l'intérieur d'un chapeau (176) dudit connecteur (168), et lesdits conducteurs externes (160) se terminant en une connexion avec des lignes conductrices (170) à l'intérieur dudit chapeau (176), ledit conducteur central (172) et lesdites lignes conductrices (170) pouvant en outre être connectés aux électrodes dudit dispositif d'allumage.

15

20

25

6. Appareil selon la revendication 1, caractérisé en ce que le condensateur est formé par un conducteur intérieur et un conducteur extérieur (127, 128) d'un câble de distribution coaxial (123) qui se termine dans un connecteur (138) ayant une partie de connexion électrique (140) pour connecter les électrodes du dispositif d'allumage aux conducteurs (127, 128) dudit câble de distribution coaxial (123).

30

35

40

45

50

55

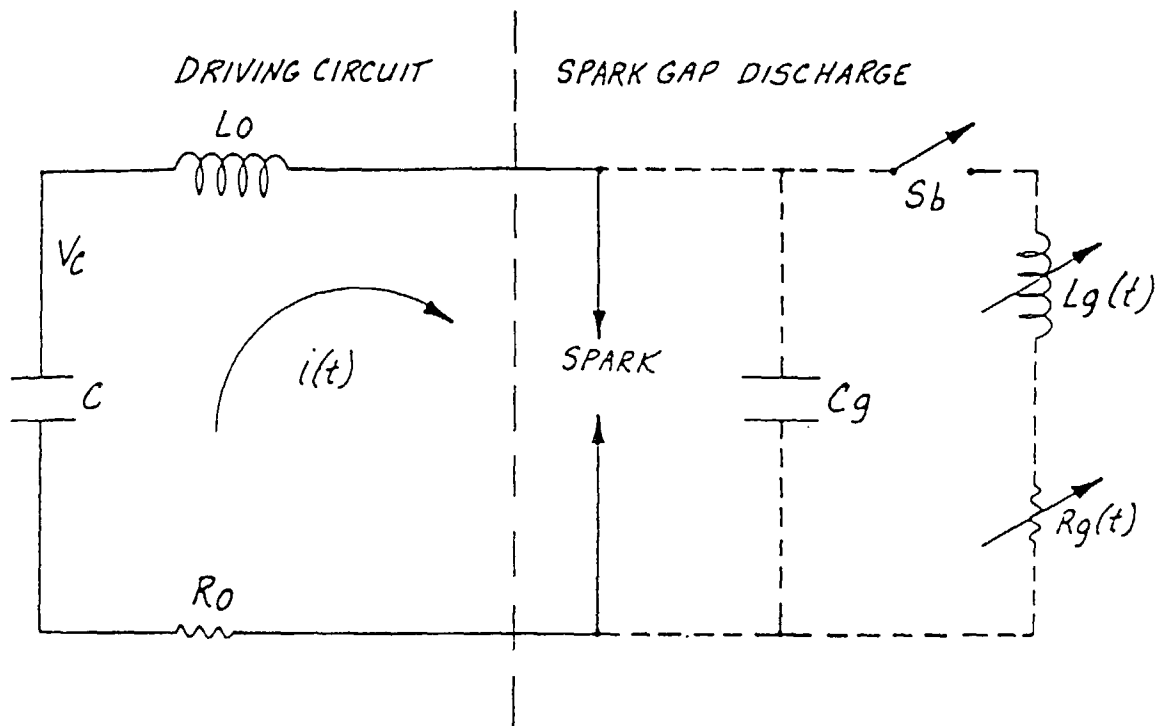
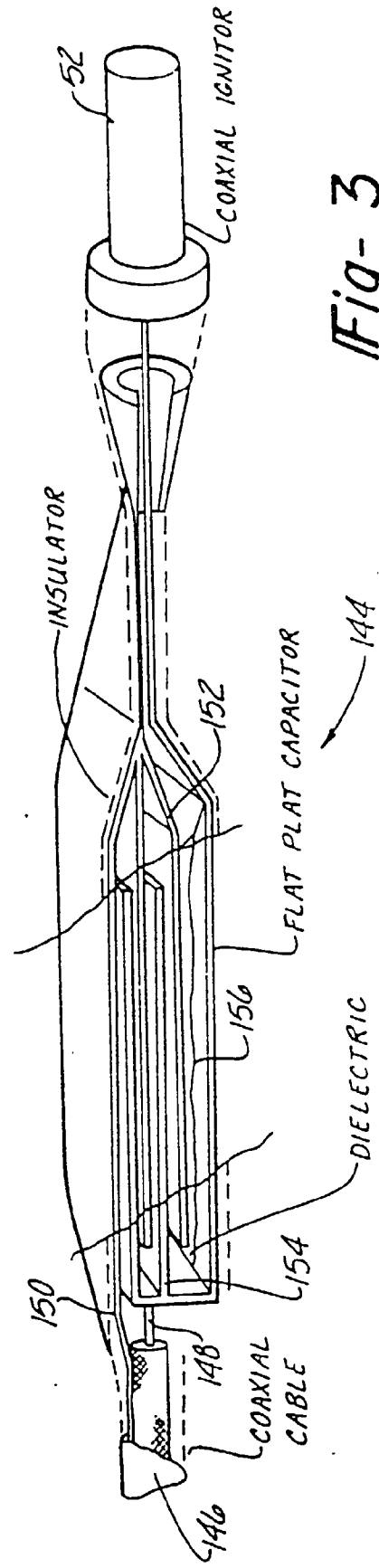
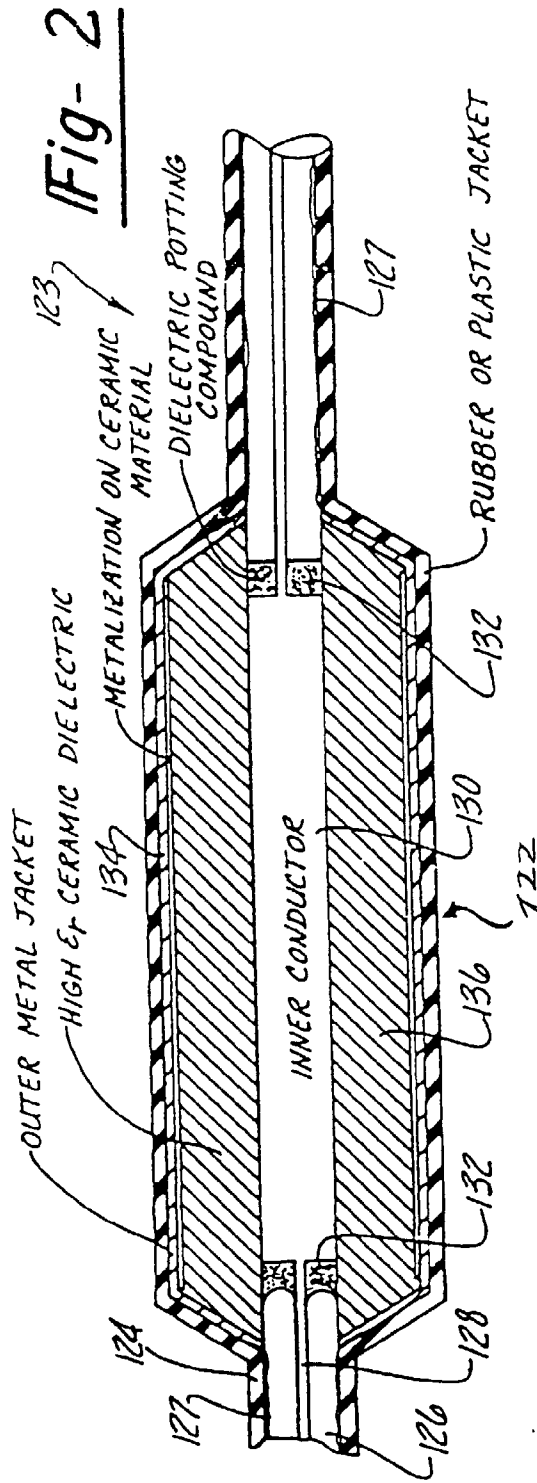
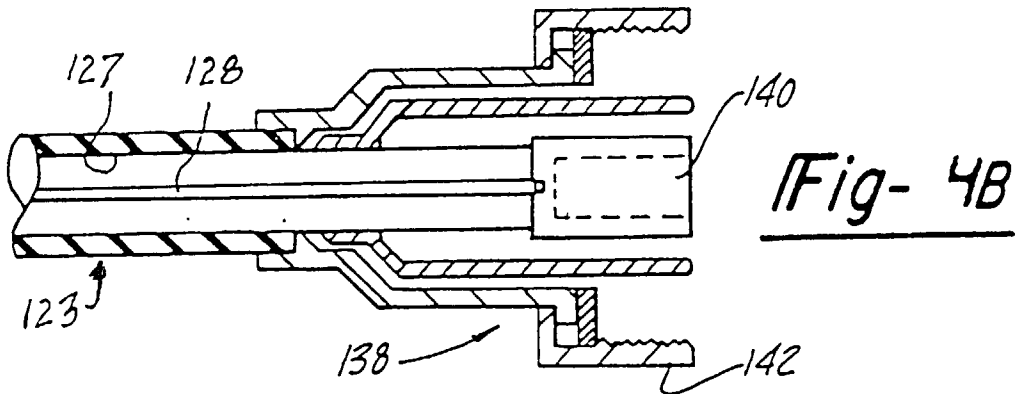
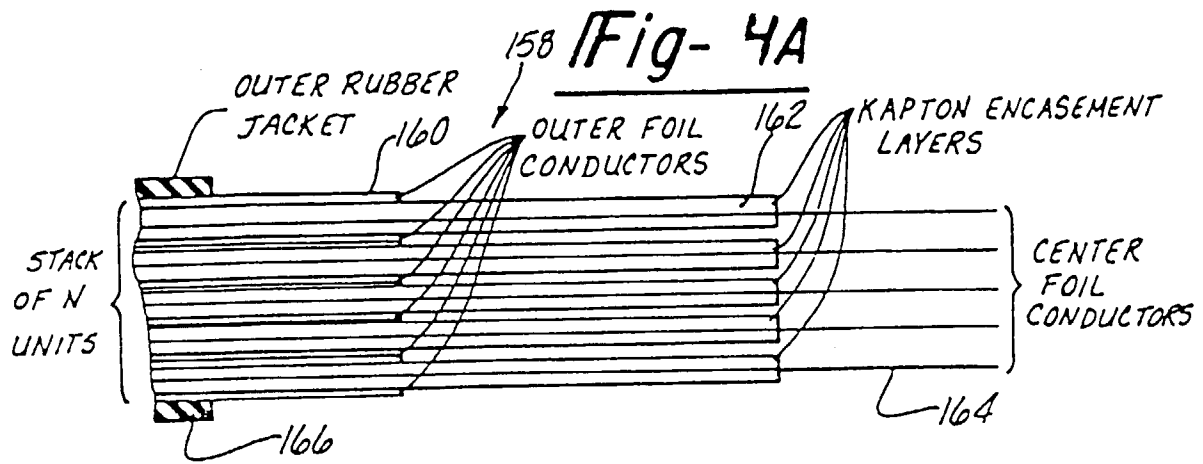


Fig-1





POSSIBLE STRIPLINE TERMINATION-
CONNECTOR

