OPIC
OFFICE DE LA PROPRIÉTÉ INTELLECTUELLE DU CANADA

CIPO
CANADIAN INTELLECTUAL PROPERTY OFFICE

(12) (19) (CA) **Demande-Application**

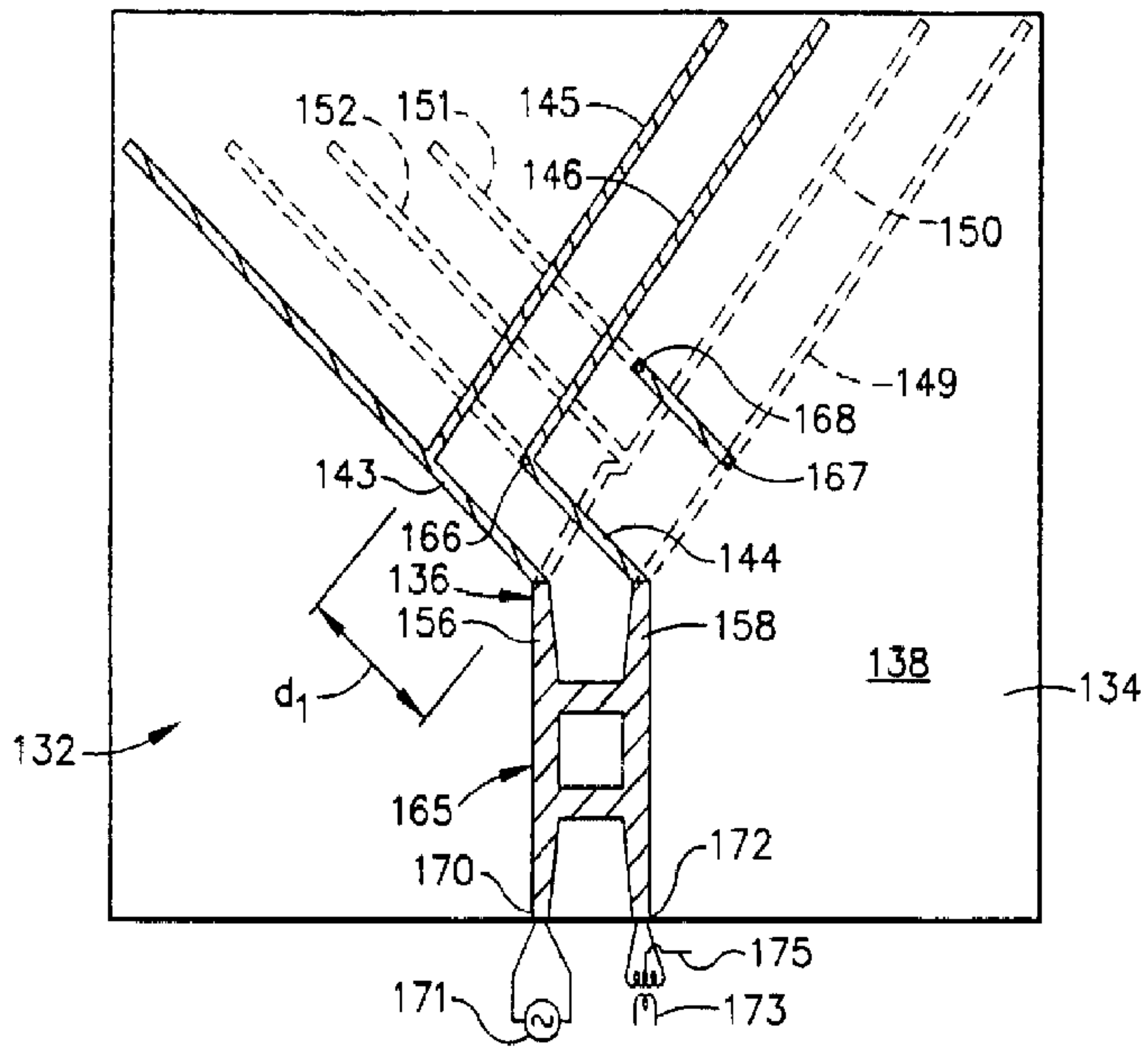
(21) (A1) **2,275,694**
(86) 1997/12/19
(87) 1998/07/02

(72) DENT, PAUL W., US
(72) HASSAN, AMER, US
(72) MACDONALD, JAMES D., JR., US
(72) MA, YAWEI, US
(71) ERICSSON INC., US

(51) Int.Cl.[6] H01Q 1/24
(30) 1996/12/24 (08/773,661) US

(54) **SYSTEME ANTENNE POUR SATELLITE DOUBLE MODE/TELEPHONE PORTABLE CELLULAIRE**

(54) **ANTENNA SYSTEM FOR DUAL MODE SATELLITE/CELLULAR PORTABLE PHONE**



(57) L'invention concerne une antenne pouvant fonctionner dans deux bandes de fréquence différentes. L'antenne comprend une première hélice quadrifilaire constituée de quatre éléments conducteurs disposés en hélice, de façon à définir un cylindre ayant un diamètre sensiblement constant, et formée de deux hélices bifilaires disposées perpendiculairement et excitées en quadrature de phase. Un réseau d'alimentation en quadrature est connecté à la première hélice quadrifilaire, une extrémité d'un élément de couplage étant connectée à une première extrémité de chaque élément conducteur. Le réseau d'alimentation en

(57) An antenna operable in two disparate frequency bands is disclosed as including a first quadrifilar helix having four conductive elements arranged helically to define a cylinder of substantially constant radius, where the first quadrifilar helix is formed of two bifilar helices arranged orthogonally and excited in phase quadrature. A quadrature feed network is connected to the first quadrifilar helix, wherein one end of a coupling element thereof is connected to a first end of each conductive element. The quadrature feed network also includes a first feedpoint for operation of the antenna with circular polarization in a first frequency band and a second

OPIC
Office de la propriété intellectuelle du Canada

CIPO
Canadian Intellectual Property Office

(21) (A1) **2,275,694**
(86) 1997/12/19
(87) 1998/07/02

quadrature comporte également un premier point d'alimentation pour le fonctionnement de l'antenne avec une polarisation circulaire dans une première bande de fréquence et un second point d'alimentation pour le fonctionnement de l'antenne avec une polarisation linéaire dans une seconde bande de fréquence. L'antenne peut comprendre une seconde hélice quadrifilaire connectée au réseau d'alimentation en quadrature, constituée de quatre éléments conducteurs disposés en hélice, de façon à définir un cylindre ayant un diamètre sensiblement constant, et formée de deux hélices bifilaires disposées perpendiculairement et excitées en quadrature de phase. La seconde hélice quadrifilaire est enroulée dans le sens opposé à celui de la première hélice quadrifilaire, de façon à être couplée de manière conductrice avec elle.

feedpoint for operation of the antenna with linear polarization in a second frequency band. The antenna may include a second quadrifilar helix connected to the quadrature feed network and having four conductive elememts arranged helically to define a cylinder of substantially constant radius, where the second quadrifilar helix is formed by two bifilar helices arranged orthogonally and excited in phase quadrature. The second quadrifilar helix is wound in opposite sense with respect to the first quadrifilar helix so as to be conductively coupled therewith.

CA 02275694 1999-06-22

CORRECTED VERSION*

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01Q 1/24 | A1

(11) International Publication Number: WO 98/28814

(43) International Publication Date: 2 July 1998 (02.07.98)

(21) International Application Number: PCT/US97/23683

(22) International Filing Date: 19 December 1997 (19.12.97)

(30) Priority Data:
08/773,661 24 December 1996 (24.12.96) US

(71) Applicant: ERICSSON INC. [US/US]; 7001 Development Drive, P.O.Box 13969, Research Triangle Park, NC 27709 (US).

(72) Inventors: DENT, Paul, W.; 637 Eaglepoint Road, Pittsboro, NC 27312 (US). HASSAN, Amer; 12627 N.E. 107th Place, Kirkland, WA 98033 (US). MacDONALD, James, D., Jr.; 134 Parkcrest Drive, Apex, NC 27502 (US). MA, Yawei; 115 Chestone Court, Cary, NC 27607 (US).

(74) Agents: DAVIDSON, James, P. et al.; Davidson & Gribbell, Suite 120, 10250 Alliance Road, Cincinnati, OH 45242 (US).

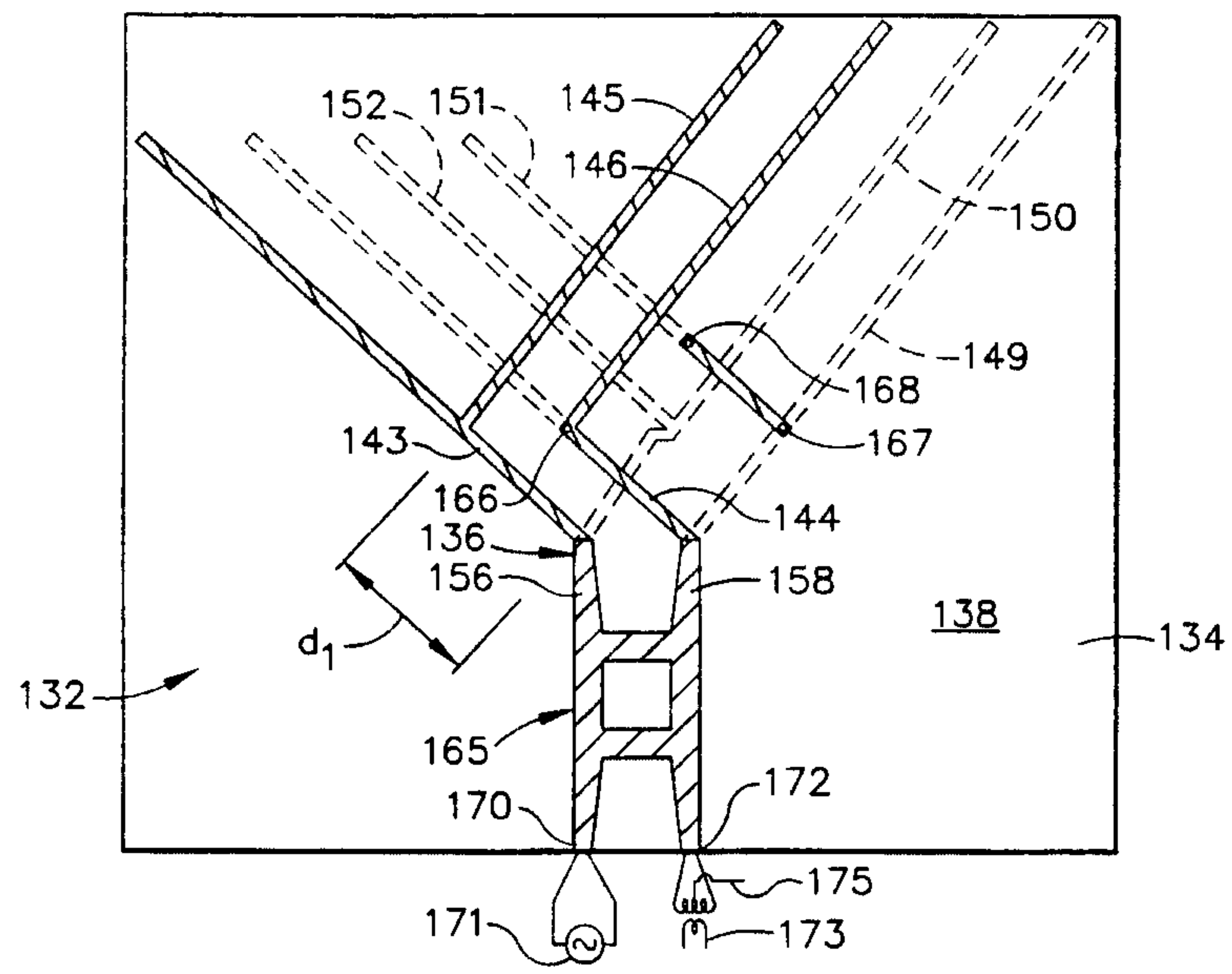
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: ANTENNA SYSTEM FOR DUAL MODE SATELLITE/CELLULAR PORTABLE PHONE

(57) Abstract

An antenna operable in two disparate frequency bands is disclosed as including a first quadrifilar helix having four conductive elements arranged helically to define a cylinder of substantially constant radius, where the first quadrifilar helix is formed of two bifilar helices arranged orthogonally and excited in phase quadrature. A quadrature feed network is connected to the first quadrifilar helix, wherein one end of a coupling element thereof is connected to a first end of each conductive element. The quadrature feed network also includes a first feedpoint for operation of the antenna with circular polarization in a first frequency band and a second feedpoint for operation of the antenna with linear polarization in a second frequency band. The antenna may include a second quadrifilar helix connected to the quadrature feed network and having four conductive elememts arranged helically to define a cylinder of substantially constant radius, where the second quadrifilar helix is formed by two bifilar helices arranged orthogonally and excited in phase quadrature. The second quadrifilar helix is wound in opposite sense with respect to the first quadrifilar helix so as to be conductively coupled therewith.



*(Referred to in PCT Gazette No. 50/1998, Section II)

ANTENNA SYSTEM FOR DUAL MODE SATELLITE/CELLULAR PORTABLE PHONE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a dual mode satellite/cellular portable phone and, in particular, to an antenna system for a dual mode satellite/cellular portable phone.

2. Description of Related Art

Portable cellular phones are well known and have been utilized for the past several years. Such cellular phones typically transmit and receive signals at a frequency of approximately 800-950 Megahertz by means of an antenna designed for such purpose. Recently, however, it has become desirable for a second mode of communication, (e.g., satellite) to be employed in areas where cellular towers or stations are not available. Satellite communication occurs at frequencies much higher than for cellular communication (typically 1.0-3.0 Gigahertz) and likewise requires an antenna specifically designed for such communication. It will be understood that there are certain differences between an antenna utilized for cellular communication versus one utilized for satellite communication. One example is that the cellular antenna will preferably be linearly polarized so as to function as a monopole while the satellite antenna is circularly polarized in order to provide hemispherical coverage. A further distinction is that communication in the satellite mode involves a directional component (where link margin is increased when the satellite antenna is pointed toward the satellite), whereas communication in the cellular mode does not.

Because at least some of the characteristics desirable for the cellular and satellite antennas are inconsistent, one approach that has been taken is the antenna system shown and disclosed in a patent application entitled "Antenna System For Dual Mode Satellite/Cellular Portable Phone," Serial No. 08/586,433, also filed by the assignee of the present invention. As seen therein, separate antennas were provided with a portable phone for cellular and satellite communication. While the antenna system disclosed by this patent application is adequate for its intended purpose, it will be noted that an antenna system having only a single antenna which can be utilized for both cellular and satellite modes of communication would be preferred from the standpoints of cost and aesthetics.

U.S. Patent 3,503,075 to Gerst discloses a broadband high gain antenna having a plurality of filament conductors where each conductor is a pair of counterwound helical windings connected at one end. The connected ends of the helical windings are fed with differently phased signals from separate signal transfer terminals to achieve different types of polarization. In this regard, the polarization of the radiation can be controlled to be linear, elliptical or circular by changing the signal feeding network of the antenna. For an octafilar counterwound helix antenna, each signal transfer terminal receives equi-amplitude signals which are mutually displaced in phase by 45 degrees (the phase relationship is directly related to the angular position of the signal transfer terminal). Linear polarization is achieved by summing the amplitude and phase vectors for right and left-hand circular polarization.

U.S. Patent 5,581,268 to Hirshfield discloses an antenna structure that includes a plurality of transmit linear elements arranged parallel to one another and a plurality of receive linear elements also arranged parallel to

AMENDED SHEET

one another. It will be seen that individual transmit linear elements are spaced apart from one another and have one of the receive linear elements disposed therebetween. In this way, a width of each of the plurality of transmit linear elements and the plurality of receive linear elements varies periodically along a length of the linear element to periodically modulate the impedance of each element. Hybrids are used to offset the RF signals in each radiator by 90° from one another (i.e.. in quadrature).

U.S. Patent 5.572.172 to Standke et al. discloses a 180° power divider for use with an antenna feed network, particularly for a feed network used with a quadrifilar helix antenna. It will be seen that a branch line coupler is provided to accept an input signal and split it into two output signals which are equal in amplitude and differ in phase by 90°. The 180° power divider similarly accepts an input signal and splits it into two output signals which are equal in amplitude and differ in phase by 180°. Depending upon whether an electrically infinite ground plane is provided on the opposite surface of the microstrip from the trace upon which the input signal travels in the power divider, the input signal is either unbalanced or balanced.

In light of the foregoing, a primary desire of the present invention is to provide an antenna system for a portable phone which enables the transmission and receipt of signals in both cellular and satellite modes of communication.

Another desire of the present invention is to provide an antenna system for a dual mode satellite/cellular portable phone which includes only a single antenna for transmitting and receiving signals in cellular and satellite modes of communication.

A further desire of the present invention is to provide an antenna system for a dual mode satellite/cellular portable phone which is mounted so as to enable better link margin with respect to an applicable satellite.

Yet another desire of the present invention is to provide an antenna system for a dual mode satellite/cellular portable phone which minimizes the need for manipulation by the user thereof.

AMENDED SHEET

Still another desire of the present invention is to provide an antenna system for a dual mode satellite/cellular portable phone which is aesthetically pleasing to the user thereof.

Another desire of the present invention is to provide an antenna system for a dual mode satellite/cellular portable phone which minimizes the overall impact on size of the portable phone.

A still further desire of the present invention is to provide an antenna system for a dual mode satellite/cellular portable phone which permits the use of separate frequency sub-bands for transmitting and receiving signals within the satellite and cellular modes of communication.

These desires and other features of the present invention will become more readily apparent upon reference to the following description when taken in conjunction with following drawing.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, an antenna operable in two disparate frequency bands is disclosed as including a first quadrifilar helix having four conductive elements arranged helically to define a cylinder of substantially constant radius, where the first quadrifilar helix is formed of two bifilar helices arranged orthogonally and excited in phase quadrature. A quadrature feed network is connected to the first quadrifilar helix, wherein one end of a coupling element thereof is connected to a first end of each conductive element. The quadrature feed network also includes a first feedpoint connected to a first pair of the conductive elements, the coupling element being balanced and the first quadrifilar helix having circular polarization, wherein the antenna is operable in a first frequency band and a second feedpoint connected to a second pair of the conductive elements, the coupling element being unbalanced and the first quadrifilar helix having linear polarization, wherein the antenna is operable in a second frequency band. The antenna may include a second quadrifilar helix connected to the quadrature feed network and having four conductive

AMENDED SHEET

elements arranged helically to define a cylinder of substantially constant radius, where the second quadrifilar helix is formed by two bifilar helices arranged orthogonally and excited in phase quadrature. The second quadrifilar helix is wound in opposite sense with respect to the first quadrifilar helix so as to be electromagnetically decoupled therefrom.

In accordance with a second aspect of the present invention, an antenna for transmitting and receiving signals within a first frequency band and a second frequency band is disclosed as including a flexible sheet of film having a first side and a second side, a first metallized pattern formed on the first side of the film sheet having a plurality of spiral arms connected to a coupler, and a second metallized pattern formed on the second side of the film sheet having a plurality of spiral arms connected to a coupler. The film sheet is formed into a cylindrical tube having a longitudinal axis therethrough so that a first coaxial quadrifilar helix is constructed by the spiral arms of the first metallized pattern and a second coaxial quadrifilar helix is constructed by the spiral arms of the second metallized pattern, with the first and second quadrifilar helices being wound in an opposite sense to avoid electromagnetic coupling therebetween.

In accordance with a third aspect of the present invention, a portable phone having RF circuitry contained within a main housing for operating the portable phone in both cellular and satellite modes is disclosed. More specifically, an antenna assembly for such portable phone is disclosed as including a base member connected to a top portion of the main housing of the portable phone and a radome member rotatably connected to the base member, where the radome member contains therein a printed antenna which is able to transmit and receive signals in the cellular and satellite modes of operation. The antenna assembly may also include a hinge member connected to the radome member which is rotatably engaged to the base member, wherein the radome member is rotatable about an axis between a first position adjacent a side surface of the main housing and a second position. Additionally, an elbow member is preferably connected to the hinge member at a first end and the radome member at a second end so that the hinge and radome members are substantially perpendicular in orientation.

In accordance with a fourth aspect of the present invention, a quadrifilar helix antenna is disclosed as including a flexible sheet of dielectric film with first and second pairs of conductive arms printed upon the flexible sheet of dielectric film in such manner that the conductive arms form a quadrifilar helix when the flexible sheet is rolled into a cylindrical tube. A balanced 90° branch line coupler is also printed on the flexible sheet of dielectric film, wherein the coupler is able to provide two balanced output signals in phase quadrature relative to each other. The coupler further includes a first output port connected to the first pair of conductive arms which has a first terminal for providing an in-phase portion of a first output signal to one of the first pair of conductive arms and a second terminal for providing an anti-phase portion of the first output signal to the other of the first pair of conductive arms. The coupler also includes a second output port connected to the second pair of conductive arms in which the second output port has a first terminal for providing an in-phase portion of a second output signal to one of the second pair of conductive arms and a second terminal for providing an anti-phase portion of the second output signal to the other of the second pair of conductive arms. The coupler has at least one input port for receiving an input signal and splitting the input signal between the first and second pairs of conductive arms in relative phase progression so as to be radiated with circular wave polarization.

BRIEF DESCRIPTION OF THE DRAWING

While the specification concludes with claims particularly pointing out and distinctly claiming the present invention, it is believed the same will be better understood from the following description taken in conjunction with the accompanying drawing in which:

Fig. 1 is a perspective view of a handheld portable phone operable in both satellite and cellular modes of communication including the antenna assembly of the present invention, where the radome member of the antenna assembly is in a first position;

Fig. 2 is a perspective view of the handheld portable phone depicted in Fig. 1, where the radome member of the antenna assembly is in a second position;

Fig. 3 is an exploded, perspective view of the antenna assembly with the portable phone depicted in Figs. 1 and 2;

Fig. 4 is a bottom perspective view of the base member for the antenna assembly depicted in Figs. 1-3;

Fig. 5 is a planar front view of a first embodiment for the printed antenna located within the radome member of the antenna assembly depicted in Figs. 1-3;

Fig. 6 is a planar rear view of the printed antenna depicted in Fig. 5;

Fig. 7 is a front view of the printed antenna depicted in Figs. 5 and 6 after being formed into a cylindrical tube configuration, where electrical elements associated with the various feedpoints of the antenna are schematically depicted;

Fig. 8 is a planar front view of a second embodiment for the printed antenna located within the radome member of the antenna assembly depicted in Figs. 1-3, where electrical elements associated with the various feedpoints of the antenna are schematically depicted;

Fig. 9 is a planar rear view of the printed antenna depicted in Fig. 8, where the electrical elements associated with the various feedpoints of the antenna are also schematically depicted; and

Fig. 10 is a front view of the printed antenna depicted in Figs. 8 and 9 after being formed into a cylindrical tube configuration.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawing in detail, wherein identical numerals indicate the same elements throughout the figures, Fig. 1 depicts a handheld portable phone 10 which is operable in the dual modes of satellite and cellular communication. It will be seen that portable phone 10 has a main housing 12 and preferably an antenna assembly 14 in accordance with the present invention which transmits and receives signals within certain specified frequency bands of operation. A keypad 16, display 18, and speaker 20 are provided along a front surface 22 of main housing 12 to permit a user to operate portable phone 10 in the normal manner. Of course, it will be understood that main housing 12 has RF circuitry located therein enabling portable phone 10 to communicate in both the cellular and satellite modes of communication. While not shown, exemplary RF circuitry is shown and described in a patent application entitled "Dual Mode Satellite/Cellular Terminal," Serial No. 08/501,575, which is owned by the assignee of the present invention.

With respect to antenna assembly 14, it will be noted from Figs. 1 and 2 that it preferably is located adjacent to a top surface 24 (see Fig. 3) and one side surface 26 of main housing 12 and therefore has a substantially L-shaped configuration (although it could just as easily be located along the other side of main housing 12). Antenna assembly 14 is preferably detachably secured to main housing 12 and includes a base member 28 connecting antenna assembly 14 to main housing 12, a radome member 30 containing a printed antenna 32 therein (to be discussed in greater detail hereinafter), a hinge member 34 which enables radome member 30 to rotate about an axis 36 between a first position adjacent side surface 26 (shown in Fig. 1) to a second position substantially 180° from the first position (shown in Fig. 2), and an elbow member 38 which connects radome member 30 to hinge member 34 and rotates about axis 36 in conjunction with radome member 30. It will be understood that radome member 30 is maintained in the first position when it is not in use or in a standby mode to minimize the overall size of portable phone 10, as antenna assembly 14 will slightly increase the overall height and width of portable phone 10 from that of main housing 12. In this first position, the impact on ease of holding and transporting portable phone 10 is minimized. Otherwise, radome member 30 and elbow member 38 of antenna assembly 14 are rotated to the second position when used to transmit or receive signals.

As indicated hereinabove, antenna assembly 14 preferably is detachably mounted to main housing 12 by means of base member 28. Accordingly, base member 28 may be constructed similarly to a support bracket assembly used to detachably mount a flip cover to the main housing of a portable phone shown and described in a patent application entitled "Detachable Flip Cover Assembly For A Portable Phone," Serial No. 08/586,434, which is owned by the assignee of the present invention. Thus, as shown in Figs. 3 and 4, base member 28 preferably includes a first slotted portion 40 which is sized to receive top surface 24 and a portion of main housing 12. A latching mechanism, preferably in the form of a detent 42 which is positioned to be received in a recess (not shown) in a rear surface of main housing 12, is provided to couple base member 28 to main housing 12. In order to facilitate the mounting of base member 28 to main housing 12, first slotted portion 40 of base member 28 preferably has at least one guide pin 44 positioned therein which is received within a corresponding opening 46 in main housing 12, as well as a dovetail-type guide located on at least one of main housing side surfaces 26 and 50. Each dovetail-type guide includes a male member 52 located within first slotted portion 40 of base member 28 and a complementary female member 54 associated with main housing 12. Connectors 56, 58, and 60 are located within first slotted portion 40 of base member 28 and connected to one end of coaxial cables 62, 64, and 66, respectively, with the other end of coaxial cables 62, 64, and 66 being connected to printed antenna 32. Complementing this arrangement, connectors 68, 70, and 72 are coupled to the internal RF circuitry and extend from top surface 24 of main housing 12 so as to be aligned with and mated to connectors 56, 58, and 60 when base member 28 is mounted to main housing 12. In this way, the RF circuitry of portable phone 10 is properly connected to printed antenna 32 of antenna assembly 14.

Base member 28 further includes a second slotted portion 74 opposite first slotted portion 40, where hinge member 34 of antenna assembly 14 is rotatably mounted thereto. In this way, portable phone 10 permits flexibility in the positioning of printed antenna 32 by a user thereof, whereby the signal strength is maximized (when in the satellite mode of communication) by pointing printed antenna 32 toward an applicable satellite. More specifically, hinge member 34 includes a rotary joint shaft 76 that extends through a pair of rotary joint bearings 78 and 80 positioned within grooved slots 79 and 81, respectively, immediately to the interior of end walls 82 and 84 of base member 28. It will be noted that rotary joint shaft 76, as well as rotary joint bearings 78 and 80, preferably has a D-shaped cross-section in order to prevent radome member 30 of antenna assembly 14 from over-rotating about axis 36 (the preferred range of rotation being approximately 180° in one direction or the other). One end of rotary joint shaft 76 is preferably retained to elbow member 38 of antenna assembly 14 while the other end preferably has a swivel cap attached thereto (not shown). As seen in Fig. 3, a removable covering 88 optionally is secured to base member 28 in order to protect hinge member 34 from dirt and other contaminants.

Elbow member 38 of antenna assembly 14 has rotary joint shaft 76 connected thereto at a first end 90 and radome member 30 connected at a second end 92 (which generally will be oriented substantially 90° with respect to first end 90). As seen in Fig. 3, elbow portion 38 is hollow and includes a side opening 94 therein which is covered by a removable access cap 96. Preferably, access cap 96 is frictionally retained to elbow member 38, such as by a male-female configuration (a plurality of female portions 97 being seen in Fig. 3). Likewise, radome member 30 may be secured to second end 92 of elbow member 38 by means of a friction fit. In this regard,

Fig. 3 depicts radome member 30 as being substantially a cylindrical tube having an inner radius R_1 slightly greater than an outer radius R_2 of cylindrical second end 92 of elbow member 38, where radome member 30 is able to slide over such cylindrical second end 92 until it is seated against a lip 98.

It will be understood that the hollow nature of both rotary joint shaft 76 and elbow member 38 enables coaxial cables 62, 64 and 66 to be connected to printed antenna 32 in radome member 30 at one end and to connectors 56, 58 and 60 at the other end by means of openings (not shown) in rotary joint shaft 76. In particular, signals transmitted to an applicable satellite via printed antenna 32 are sent from the RF circuitry in main housing 12 through coaxial cable 62, signals received by printed antenna 32 from an applicable satellite are sent to the RF circuitry in main housing 12 through coaxial cable 64, and coaxial cable 66 is utilized to both transmit signals to and receive signals from printed antenna 32 when portable phone 10 is in the cellular (monopole) communication mode. In order to maintain coaxial cables 62, 64, and 66 in the proper shape, as well as produce a minimum bend radius, prevent chafing of the cables and reduce fatigue failures of the jacket material under flexing conditions, it is preferred that the outer jackets thereof be heat formed as described in a patent application entitled "Coaxial Cable Assembly For A Portable Phone," Serial No. 08/613,700, which is also owned by the assignee of the present invention.

With respect to radome member 30 of antenna assembly 14, it has been noted that a printed antenna 32 preferably is located therein. Although printed antenna 32 is rolled into a cylindrical tube to be in the desired shape for radome member 30 (as seen in Fig. 7), it will be best understood by referring to the planar top and rear views thereof in Figs. 5 and 6. As seen therein, printed antenna 32 preferably is constructed of a flexible film sheet 100 made of a dielectric material (e.g., mylar, fiberglass, kevlar, or the like).

Film sheet 100 has a front surface 102 with a metallized layer 104 applied thereto in a desired pattern (see Fig. 5) and a rear surface 106 with a second metallized pattern 108 applied thereto of a predetermined design (see Fig. 6). More particularly, front metallized layer 104 has a pair of spiral arms 105 and 107 and rear metallized layer 108 has a pair of spiral arms 109 and 111 which are configured so that printed antenna 32 has a quadrifilar helix design when film sheet 100 is rolled into a cylindrical tube, as best seen in Fig. 7. It will be understood that front and rear metallized layers 104 and 108 are preferably printed on film sheet 100, with the dimensions thereof being photographically reproduced. Spiral arms 105, 107, 109, and 111, for their part, typically will have a length substantially equivalent to either a quarter wavelength or a three-quarter wavelength of the desired frequencies of operation.

It will be further understood that the cylindrical tube into which film sheet 100 is rolled preferably has a controlled diameter D (see Fig. 7). One approach for performing this task is to wrap film sheet 100 about a mandrel and glue the overlapping portions which extend more than 360°. The mandrel would then be removed once the glue has dried. By so forming film sheet 100, it will be seen that a quadrifilar helix 101 is formed by spiral arms 105, 107, 109 and 111 since they are wound in the same sense.

A balanced 90° branch line coupler 110, made by printed patterns on front and rear metallized layers 104 and 108, is preferably used to provide the four-phase drive signals to spiral arms 105, 107, 109, and 111 of printed antenna 32. It will be understood that coupler 110 is an adaptation of an unbalanced branch line coupler described in U.S. Patent 4,127,831 to Riblet. Instead of the unbalanced form in Riblet where a branch line coupler pattern is printed on one side of a dielectric layer with a ground plane on the other side thereof, coupler 110 of the present invention includes two identical coupler patterns placed back-to-back on front and back surfaces 102 and 106 of dielectric film sheet 100. Coupler 110 thus has a balanced construction in which square conductors 112 (front metallized layer 104) and 114 (rear metallized layer 108) are separated by dielectric film sheet 100. Of course, coupler 110 provides the connection between printed antenna 32 and coaxial cables 62, 64, and 66 so that printed antenna 32 is connected to the RF circuitry in portable phone 10.

It will be noted from Figs. 5 and 6 that spiral arms 105 and 111 are connected to a first output of coupler 110 made up of upper legs 113 and 119 extending from square conductors 112 and 114, respectively. Likewise, spiral arms 107 and 109 are connected to a second output of coupler 110 formed by upper legs 115 and 117 extending from square conductors 112 and 114, respectively. In this way, upper legs 113 and 115 will carry the in-phase portion and upper legs 117 and 119 will carry the anti-phase portion of the output signal from coupler 110. It will further be seen from Fig. 7 that coupler 110 has a first input port 116 including lower legs 118 and 120 of square conductors 112 and 114, respectively, which printed antenna 32 uses for transmitting frequency f_1 and receiving frequency f_2 while in the satellite mode of communication (coupler 110 being balanced and quadrifilar helix 101 having circular polarization) and a second input port 122 including lower legs 124 and 126 of square conductors 112 and 114, respectively, which printed antenna 32 uses for frequency f_3 (both transmitting and receiving) while in the cellular or monopole mode of communication (coupler 110 being unbalanced and quadrifilar helix 101 having linear polarization).

More specifically, it will be seen in Fig. 7 that a dummy load 128 is provided across lower legs 124 and 126 of second input port 122 in order to terminate the balanced mode of coupler 110 at second input port 122. In this way, only satellite frequencies f_1 and f_2 are able to be used during the balanced mode of coupler 110 since their feedpoint 129 is attached to first input port 116. A short circuit 130 is provided between front and rear metallized layers 104 and 108 in order to place coupler 110 in an unbalanced mode, with feedpoint 131 being utilized for cellular frequency f_3. Short circuit 130 preferably is located approximately a quarter-wavelength away from dummy load 128 so that it appears as an open circuit.

A second embodiment for the printed antenna, designated by the numeral 132, is depicted in Figs. 8-10. As explained hereinabove with respect to printed antenna 32, a flexible film sheet 134 is provided in which a first metallized layer 136 is applied to a front surface 138 thereof and a second metallized layer 140 is applied to a rear surface 142. A first pair of spiral arms 143 and 144 are provided in accordance with metallized layer 136 and connected to upper legs 156 and 158 of a coupler 165 like that previously described. Spiral arms 143 and 144 are in substantially parallel relation as they extend from upper legs 156 and 158. After traveling a distance d_1, spiral arm 143 has a spiral arm 145 branch off therefrom substantially perpendicular thereto and spiral arm 144 likewise has a spiral arm 146 branch off substantially perpendicular thereto. It will be seen from Figs. 8 and 9 that spiral arm 143 continues along front surface 138 of film sheet 134 while spiral arm 144 enters a plated via 166 and thereafter extends in the same direction along rear surface 142 of film sheet 134.

A second set of spiral arms 149 and 150 are provided by metallized layer 140 and connected to upper legs 160 and 162 of coupler 165. Spiral arms 149 and 150 are oriented substantially parallel to each other as they extend from upper legs 160 and 162. After traveling a distance d_2, spiral arm 149 has a spiral arm 151 branch off substantially perpendicular thereto. It will be seen that spiral arm 149 enters a plated via 167 so that spiral arm 151 travels along front surface 138 of film sheet 134 until it passes spiral arm 150, after which spiral arm 151 enters another plated via 168 and extends along rear surface 142 of film sheet 134. It will also be seen that a spiral arm 152 branches off substantially perpendicularly from spiral arm 150. Accordingly, spiral arms 150 and 152 extend along rear surface 142 of film sheet 134 for a specified length. It will be understood that when film sheet 134 is wrapped into a cylindrical tube configuration, a first quadrifilar helix

148 is formed by spiral arms 143, 144, 145, and 146 of front metallized layer 136 and a second quadrifilar helix 154 is formed by spiral arms 149, 150, 151, and 152. It will be noted that none of the spiral arms for each quadrifilar helix touch where they cross, which is why plated vias 166, 167, and 168 are strategically provided. This prevents electromagnetic coupling between first and second quadrifilar helices 148 and 154. It will also be understood that both first quadrifilar helix 148 and second quadrifilar helix 154 are coaxial with a longitudinal axis 31 through printed antenna 132, with first quadrifilar helix 148 being located concentrically outside of second quadrifilar helix 154.

Since printed antenna 132 has a three-mode configuration, a feedpoint 171 for a first satellite frequency band (having a circular polarization in a given direction) is connected to a first input port 170 of coupler 165 and a feedpoint 173 for a second satellite frequency band (having a circular polarization opposite that of the first satellite frequency band) is connected to a second input port 172 of coupler 165. In this way, separate frequency bands for transmitting and receiving signals may be utilized with printed antenna 132. It will be understood that first quadrifilar helix 148 is preferably adapted to the lower of the frequency bands and that second quadrifilar helix 154 is adapted to the higher of the frequency bands (since spiral arms 143, 144, 145 and 146 are longer than spiral arms 149, 150, 151, and 152). Of course, coupler 165 is in a balanced mode when either the first frequency band or the second frequency band are provided to printed antenna 132 in order to provide circular polarization. By contrast, a third frequency band used for transmitting and receiving cellular signals is provided printed antenna 132 when coupler 165 is in an unbalanced mode, where one of first quadrifilar helix 148 and second quadrifilar helix 154 is linearly polarized as a monopole and the other acts as a parasitic element. Accordingly, the third frequency band may utilize either first input port 170 or second input port 172 as its feedpoint 175 (although it is shown as being connected to second input port 172 in Figs. 8 and 9).

Having shown and described the preferred embodiment of the present invention, further adaptations of the antenna assembly described herein can be accomplished by appropriate modifications by one of ordinary skill in the art without departing from the scope of the invention.

What is claimed is:

1. An antenna (32) operable in two disparate frequency bands, comprising:

(a) a first quadrifilar helix (101) including four conductive elements (105,107,109,111) arranged helically to define a cylinder of substantially constant radius, said first quadrifilar helix (101) being formed of two bifilar helices arranged orthogonally and excited in phase quadrature; and

(b) a quadrature feed network connected to said first quadrifilar helix (101), wherein one end (113,115,117,119) of a coupling element (110) thereof is connected to a first end of each said conductive element (105,107,109,111);

said antenna (32) being characterized by said quadrature feed network further comprising:

(1) a first feedpoint (129) connected to a first pair (105,111) of said conductive elements, said coupling element (110) being balanced and said first quadrifilar helix (101) having circular polarization, wherein said antenna (32) is operable in a first frequency band; and

(2) a second feedpoint (131) connected to a second pair (107,109) of said conductive elements, said coupling element (110) being unbalanced and said first quadrifilar helix (101) having linear polarization, wherein said antenna (32) is operable in a second frequency band.

2. The antenna (32) of claim 1, wherein said first frequency band is within a satellite mode of operation.

3. The antenna (32) of claim 1, wherein said second frequency band is within a cellular mode of operation.

4. The antenna (32) of claim 1, said antenna (32) further comprising a sheet (100) of dielectric material, wherein said conductive elements (105,107,109,111) and said coupling element (110) are printed thereon.

5. The antenna (32) of claim 4, wherein said first pair (105,107) of said conductive elements are printed on a first surface (104) of said dielectric sheet (100) and said second pair (109,111) of said conductive elements are printed on a second surface (108) of said dielectric sheet (100).

6. The antenna (132) of claim 1, further comprising a second quadrifilar helix (154) connected to said quadrature feed network and having four conductive elements (149,150,151,152) arranged helically to define a cylinder of substantially constant radius, said second quadrifilar helix (154) being formed of two bifilar helices arranged orthogonally and excited in phase quadrature, wherein said second quadrifilar helix (154) is wound in an opposite direction from said first quadrifilar helix (148) with respect to a longitudinal axis (31) for said helices.

7. The antenna (132) of claim 6, wherein said respective conductive elements (143,144,145,146 and 149,150,151,152) of said first and second quadrifilar helices (148,154) are conductively coupled.

8. The antenna (132) of claim 6, wherein the lengths of said conductive elements (143,144,145,146) for said first quadrifilar helix (148) are greater than the lengths of said conductive elements (149,150,151,152) for said second quadrifilar helix (154).

9. The antenna (132) of claim 6, wherein said second quadrifilar helix (154) is positioned concentrically inside said first quadrifilar helix (148).

10. The antenna (132) of claim 9, wherein said frequency band within which said second quadrifilar helix (154) is operable is greater than said frequency band within which said first quadrifilar helix (148) is operable.

11. The antenna (132) of claim 10, wherein said first quadrifilar helix (148) is utilized to transmit signals during a satellite mode of operation.

12. The antenna (132) of claim 10, wherein said second quadrifilar helix (154) is utilized to receive signals during a satellite mode of operation.

13. The antenna (132) of claim 6, wherein the radius of said first quadrifilar helix (148) is greater than the radius of said second quadrifilar helix (154).

14. The antenna (132) of claim 6, wherein one of said first and second quadrifilar helices (148,154) is fed with a different circular mode so that said antenna (132) is operable in a monopole mode within a third frequency band.

15. The antenna (132) of claim 6, wherein one of said first and second quadrifilar helices (148,154) is fed with a different circular mode and the other of said helices acts as a parasitic element so that said antenna (132) is operable in a monopole mode within a third frequency band.

16. The antenna (132) of claim 15, wherein said conductive elements of said driven quadrifilar helix are fed in phase.

AMENDED SHEET

17. The antenna (132) of claim 6, said quadrature feed network further comprising a balanced 90° branchline coupler (112,114) connected to said first and second quadrifilar helices (148,154).

18. The antenna (132) of claim 6, said first and second quadrifilar helices (148,154) further comprising a dielectric film (134) with a metallized pattern (136,140) formed on each side (138,142) thereof, said film (134) being wrapped and fixed in a cylindrical shape.

19. The antenna (132) of claim 6, said quadrature feed network further comprising a third feedpoint (175) for a third frequency band.

20. An antenna (132) for transmitting and receiving signals within a first frequency band and a second frequency band including a flexible sheet (134) of film having a first side (138) and a second side (142), a first metallized pattern (136) formed on said first side (138) of said film sheet (134) having a plurality of spiral arms (143,144,145,146) connected to a coupler (112), and a second metallized pattern (140) formed on said second side (142) of said film sheet (134) having a plurality of spiral arms (149,150,151,152) connected to a coupler (114), wherein said film sheet (100) is formed into a cylindrical tube having a longitudinal axis (31) therethrough so that a first coaxial quadrifilar helix (148) is constructed by said spiral arms (143,144,145,146) of said first metallized pattern (136) and a second coaxial quadrifilar helix (154) is constructed by said spiral arms (149,150,151,152) of said second metallized pattern (140), said antenna (132) being characterized by said first and second quadrifilar helices (148,154) being wound in opposite directions with respect to said longitudinal axis (31) to avoid electromagnetic coupling therebetween.

21. The antenna (132) of claim 20, wherein said first and second quadrifilar helices (148,154) are conductively coupled to provide opposite sense circular polarization in said first and second frequency bands.

22. The antenna (132) of claim 20, wherein said film sheet (134) is made of a dielectric material.

23. The antenna (132) of claim 20, wherein the lengths of said spiral arms (143,144,145,146) of said first quadrifilar helix (148) are greater than the lengths of said spiral arms (149,150,151,152) of said second quadrifilar helix (154).

24. The antenna (132) of claim 20, wherein said second quadrifilar helix (154) is positioned concentrically inside said first quadrifilar helix (148).

25. The antenna (132) of claim 24, wherein said first quadrifilar helix (148) is utilized to transmit signals during a satellite mode of operation.

26. The antenna (132) of claim 24, wherein said second quadrifilar helix (154) is utilized to receive signals during a satellite mode of operation.

27. The antenna (132) of claim 20, wherein the radius of said first quadrifilar helix (148) is greater than the radius of said second quadrifilar helix (154).

28. The antenna (132) of claim 20, wherein one of said first and second quadrifilar helices (148,154) is fed with a different circular mode so that said antenna (132) is operable in a monopole mode within a designated frequency band.

29. The antenna (132) of claim 20, further comprising a quadrature feed network connected to said first and second quadrifilar helices (148,154).

30. In a portable phone (10) having RF circuitry contained within a main housing (12) for operating said portable phone (10) in both cellular and satellite modes, an antenna assembly (14) being characterized by:

(a) a base member (28) connected to a top portion (24) of said portable phone main housing (12); and

(b) a radome member (30) rotatably connected to said base member (28), said radome member (30) containing a printed antenna (32) therein which is able to transmit and receive signals in said cellular and satellite modes of operation.

31. The antenna assembly (14) of claim 30, further comprising a hinge member (34) connected to said radome member (30) which is rotatably engaged to said base member (28), wherein said radome member (30)is rotatable about an axis (36) between a first position adjacent a side surface (26) of said main housing (12) and a second position.

32. The antenna assembly (14) of claim 31, further comprising an elbow member (38) connected to said hinge member (34) at a first end (90) and connected to said radome member (30) at a second end (92).

33. The antenna assembly (14) of claim 32, wherein said radome member (30) is oriented substantially perpendicular to said hinge member (28).

34. The antenna assembly (14) of claim 32, wherein said antenna assembly (14) is substantially L-shaped.

35. The antenna assembly (14) of claim 31, wherein said radome member (30) is located at said first position during off and standby modes of said portable phone (10).

36. The antenna assembly (14) of claim 31, wherein said radome member (30) is located at said second position during transmission and reception of signals.

37. The antenna assembly (14) of claim 30, wherein said base member (28) is detachably mounted to said main housing (12) of said portable phone (10).

38. The antenna assembly (14) of claim 30, wherein said radome member (30) is shaped substantially as a cylindrical tube.

39. The antenna assembly (14) of claim 32, further comprising a plurality of coaxial cables (62,64,66) connected to said printed antenna (32) in said radome member (30) at one end (56,58,60) and to corresponding connectors (68,70,72) located on said main housing (12) at a second end, wherein said printed antenna (32) is connected to said RF circuitry.

40. The antenna assembly (14) of claim 39, said coaxial cables (62,64,66) being positioned through said radome member (30), said elbow member (38), said hinge member (34) and said base member (28).

41. The antenna assembly (14) of claim 31, said axis of rotation (36) for said antenna assembly (14) being oriented substantially parallel to a top surface (24) of said main housing (12).

42. The antenna assembly (14) of claim 32, said elbow member (38) further comprising an access opening (94) therein and an access cap (96) removably mounted thereto.

43. The antenna assembly (14) of claim 30, said printed antenna (32) further comprising:

(a) a flexible film sheet (100) made of dielectric material having a first side (102) and a second side (106);

(b) a first metallized pattern (104) applied to said first side (102) of said flexible film sheet (100); and

(c) a second metallized pattern (108) applied to said second side (106) of said flexible film sheet (100);

wherein at least one quadrifilar helix (101) is formed when said flexible film sheet (100) is rolled into a cylindrical tube and positioned within said radome member (30).

44. The antenna assembly (14) of claim 43, wherein said first metallized layer (104) includes a first pair of spiral arms (105,107) and said second metallized layer (108) includes a second pair of spiral arms (109,111) oriented so as to form a quadrifilar helix (101).

45. The antenna assembly (14) of claim 44, wherein said first and second pairs of spiral arms (105,107 and 109,111) have a length substantially equivalent to a quarter wavelength of a desired frequency of operation.

46. The antenna assembly (14) of claim 44, wherein said first and second pairs of spiral arms (105,107 and 109,111) have a length substantially equivalent to a three-quarter wavelength of a desired frequency of operation.

47. The antenna assembly (14) of claim 44, further comprising a coupler (110) connected to said printed antenna (32), wherein said printed antenna (32) has a circular polarization when said coupler (110) is balanced and said printed antenna (32) has a linear polarization when said coupler (110) is unbalanced.

48. The antenna assembly (14) of claim 47, said coupler (110) further comprising a first port (116) for said quadrifilar helix (101) when in a circular polarization mode and a second port (122) for said quadrifilar helix (101) when in a linear polarization mode.

49. The antenna assembly (14) of claim 48, said coupler (110) further comprising a dummy load (128) connected to said second port (122) of said coupler (110) so as to terminate the balanced mode of said coupler (110) at said second port (122).

50. The antenna assembly (14) of claim 48, further comprising a short circuit (130) between said first and second metallized layers (104,108) of said printed antenna (32), said short circuit (130) acting as a feedpoint (131) for said printed antenna (32) when said coupler (110) is in said unbalanced mode.

51. The antenna assembly (14) of claim 43, wherein said first metallized layer (136) includes a first set of spiral arms (143,144,145,146) to form a first quadrifilar helix (148) of a first designated radius and said second metallized layer (140) includes a second set of spiral arms (149,150,151,152) to form a second quadrifilar helix (154) of a second designated radius.

52. The antenna assembly (14) of claim 51, wherein said spiral arms (143,144,145,146) of said first quadrifilar helix (148) have a length greater than said spiral arms (149,150,151,152) of said second quadrifilar helix (154).

53. The antenna assembly (14) of claim 51, wherein said spiral arms (143,144,145,146) of said first quadrifilar helix (148) are wound in an opposite direction from said spiral arms (149,150,151,152) of said second quadrifilar helix (154) with respect to a longitudinal axis (31) of said cylinder tube.

54. The antenna assembly (14) of claim 51, wherein the radius of said first quadrifilar helix (148) is greater than the radius of said second quadrifilar helix (154).

55. The antenna assembly (14) of claim 51, wherein said spiral arms (143,144,145,146) of said first quadrifilar helix (148) do not touch said spiral arms (149,150,151,152) of said second quadrifilar helix (154) where they cross.

56. The antenna assembly (14) of claim 51, said first and second metallized patterns (136,140) further comprising a balanced quadrature branch-line coupler (165) connecting said printed antenna (132) to a plurality of coaxial cables (62,64,66), wherein a spiral arm from each of said first and second quadrifilar helices (148,154) is connected to each leg (56,158,160,162) of said coupler (165).

57. The antenna assembly (14) of claim 56, said printed antenna (132) further comprising a plurality of plated vias (166,167,168) in said flexible film sheet (134) so that a spiral arm (144,149,151) of said first and second metallized patterns (136,140) connected to a leg (158,160) of said coupler (165) is able to branch off, extend through one of said plated vias (166,167,16), and provide a spiral arm on the opposite metallized pattern.

58. The antenna assembly (14) of claim 56, said coupler (165) providing a first port (170) for said first quadrifilar helix (148) and a second port (172) for said second quadrifilar helix (154).

59. The antenna assembly (14) of claim 58, further comprising an open circuit (130) in one of said first and second coupler ports (170,172) so that said printed antenna (132) operates with a linear polarization when a frequency is provided thereto.

60. The antenna assembly (14) of claim 59, wherein the quadrifilar helix associated with the coupler port in which said open circuit (130) is not provided acts as a parasitic element.

61. The antenna assembly (14) of claim 56, wherein said printed antenna (132) operates with a circular polarization when said coupler (165) is in a balanced mode.

62. The antenna assembly (14) of claim 56, wherein said printed antenna (132) operates with a linear polarization when said coupler (165) is in an unbalanced mode.

63. The antenna assembly (14) of claim 51, wherein said first quadrifilar helix (148) is adapted for a signal frequency less than said second quadrifilar helix (154).

64. A quadrifilar helix antenna (101) including a flexible sheet (100) of dielectric film, a first pair (105,111) and a second pair (107,109) of conductive arms printed upon said flexible sheet (100) of dielectric film in such manner that said conductive arms (105,107,109,111) form a quadrifilar helix (101) when said flexible sheet (100) is rolled into a cylindrical tube, and a balanced 90° branch line coupler (110) printed on said flexible sheet (100) of dielectric film, wherein said coupler (110) is able to provide two balanced output signals in phase quadrature relative to each other, said helix antenna (101) being characterized by said coupler further comprising:

(a) a first output port connected to said first pair (105,111) of conductive arms, said first output port having a first terminal (113) for providing an in-phase portion of a first output signal to one (105) of said first pair of conductive arms and a second terminal (119) for providing an anti-phase portion of said first output signal to the other (111) of said first pair of conductive arms;

(b) a second output port connected to said second pair (107,109) of conductive arms, said second output port having a first terminal (115) for providing an in-phase portion of a second output signal to one (107) of said second pair of conductive arms and a second terminal (117) for providing an anti-phase portion of said second output signal to the other (109) of said second pair of conductive arms; and

(c) at least one input port (116) for receiving an input signal and splitting said input signal between said first and second pairs (105,111 and 107,109) of conductive arms in relative phase progression so as to be radiated with circular wave polarization.

65. The quadrifilar helix antenna (101) of claim 64, wherein said first pair of conductive arms (105,111) are in diametrically opposed relation and said second pair of arms (107,109) are in diametrically opposed relation.

66. The quadrifilar helix antenna (101) of claim 65, wherein said first pair of conductive arms (105,111) and said second pair of conductive arms (107,109) are interposed at approximately 90° with respect to each other.

67. The quadrifilar helix antenna (101) of claim 64, wherein one (105) of said first pair and one (107) of said second pair of conductive arms is positioned on a first surface (102) of said flexible sheet (100) and the other (111, 109) of said first and second pairs of conductive arms is positioned on a second surface (106) of said flexible sheet (100).

68. The quadrifilar helix antenna (101) of claim 64, wherein said coupler (110) has a second input port (122) which is unbalanced so that an input signal provided thereto is split between said conductive arms in a manner so as to be radiated with a linear wave polarization.

69. The antenna (32) of claim 2, wherein said antenna (32) is operable in said first frequency band for transmitting a signal and said antenna (32) is operable in a third frequency band for receiving a signal.

70. The antenna (32) of claim 3, wherein said antenna (32) is operable in said second frequency band for transmitting and receiving a signal.

71. The antenna (32) of claim 1, said quadrature feed network further comprising a dummy load (128) across said second feedpoint (131) to terminate the balancing of said coupling element (110) thereacross when a signal is provided to said first feedpoint (129).

72. The antenna (32) of claim 1, said quadrature feed network further comprising a short circuit (130) across said first and second feedpoints (129,131) to create an unbalanced condition for said coupling element (110) when a signal is provided to said second feedpoint (131).

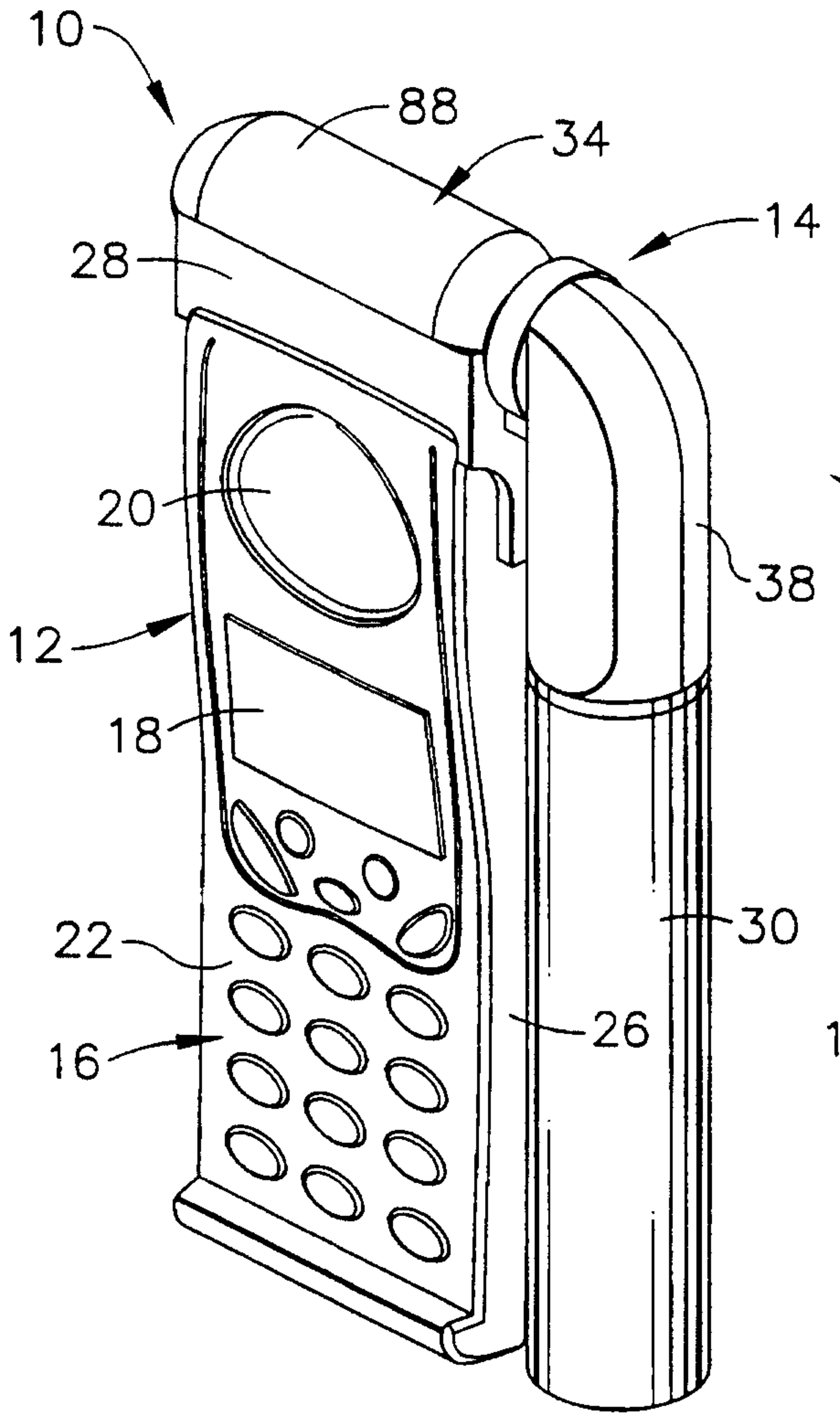

10
88
34
14
28
20
38
12
18
22
30
26
16

FIG. 1

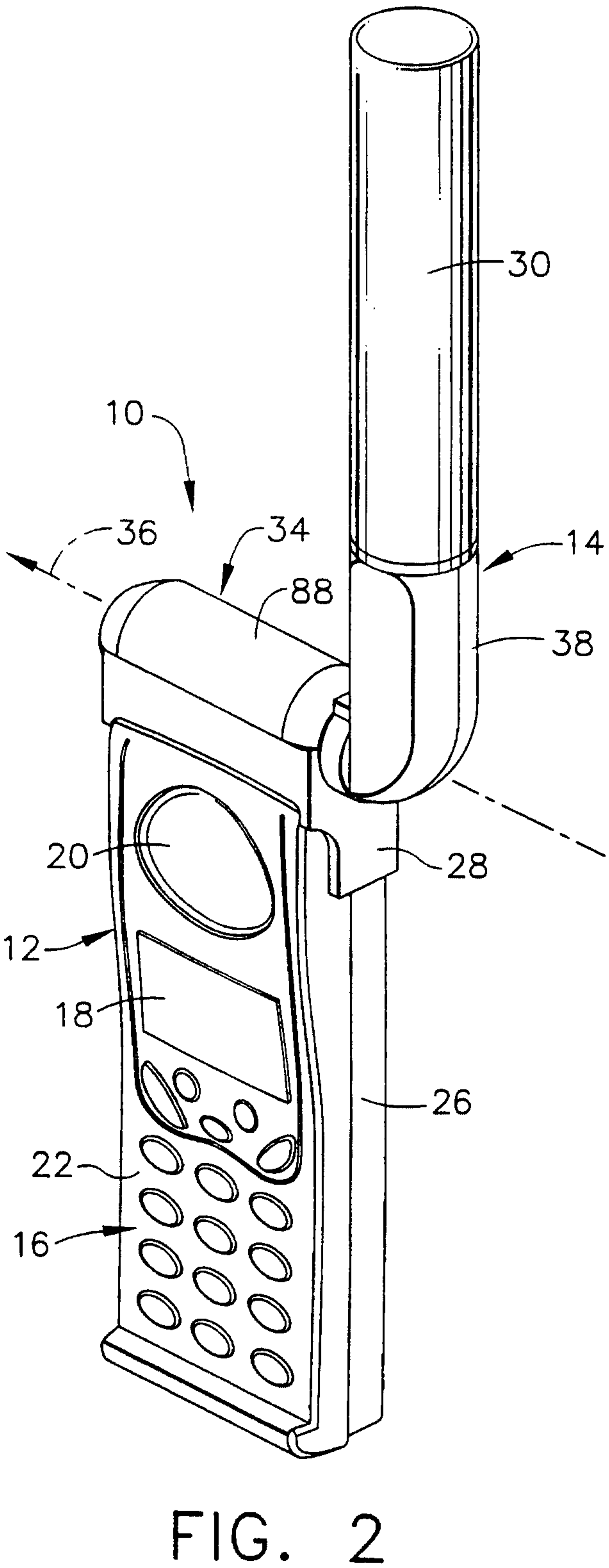

30
10
36
34
14
88
38
20
28
12
18
26
22
16

FIG. 2

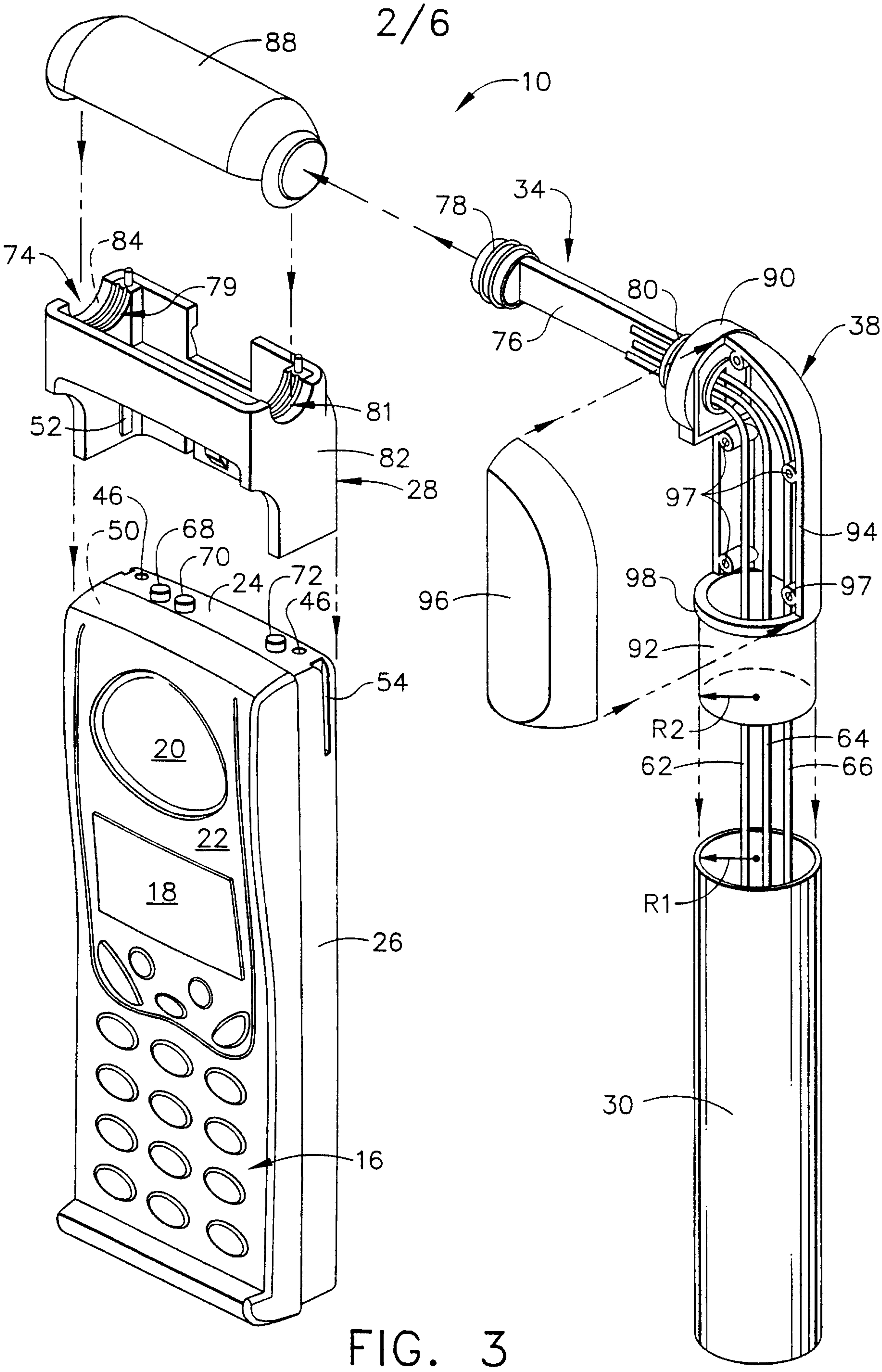

88
10
34
78
74
84
79
90
80
38
76
81
52
82
28
97
46
50
68
70
94
24
72
46
98
97
96
92
54
R2
64
62
66
20
22
18
R1
26
30
16

FIG. 3

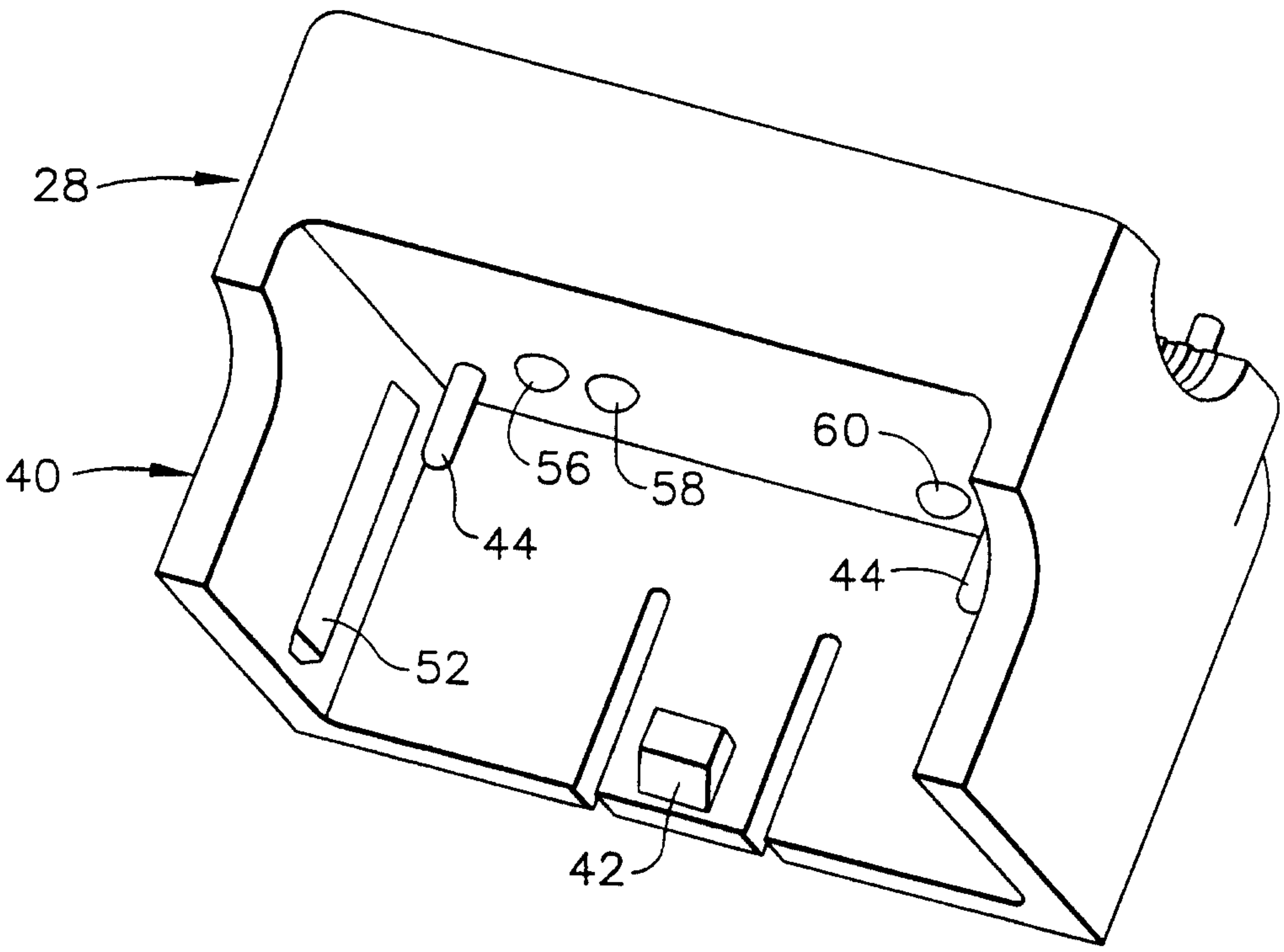


FIG. 4

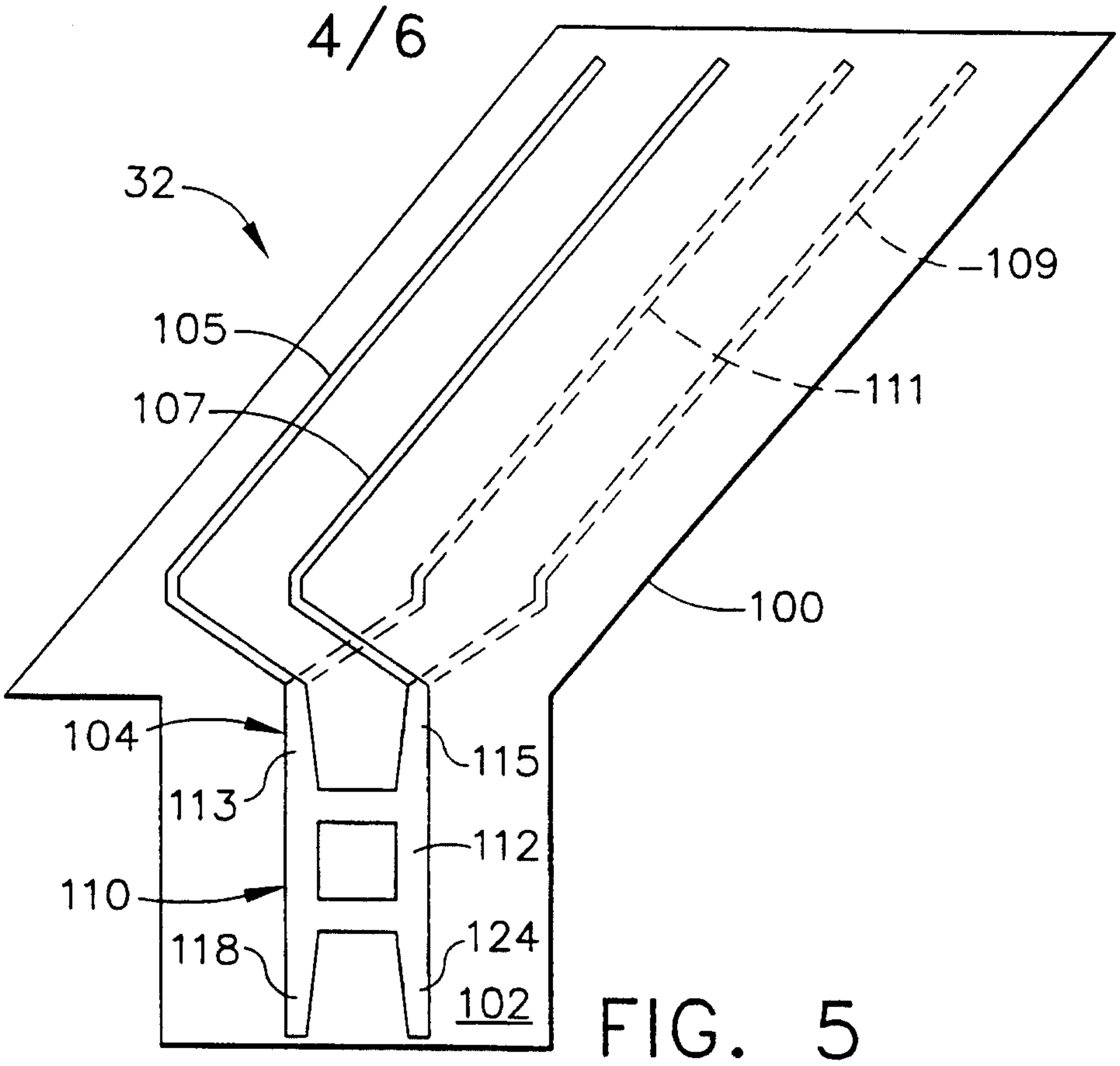

32
105
107
109
111
100
104
113
115
112
110
118
124
102

FIG. 5

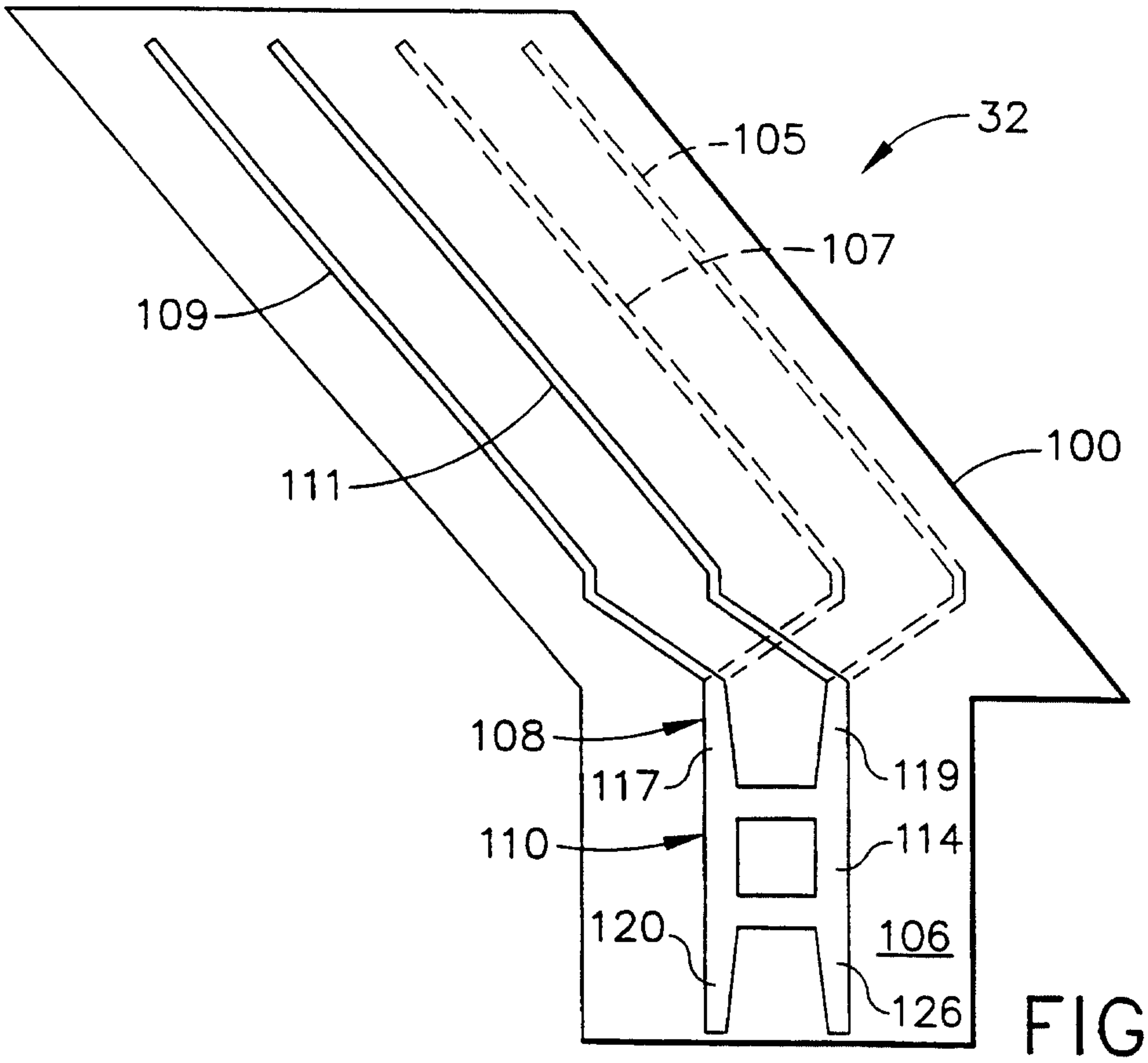

32
105
107
109
111
100
108
117
119
110
114
120
106
126

FIG. 6

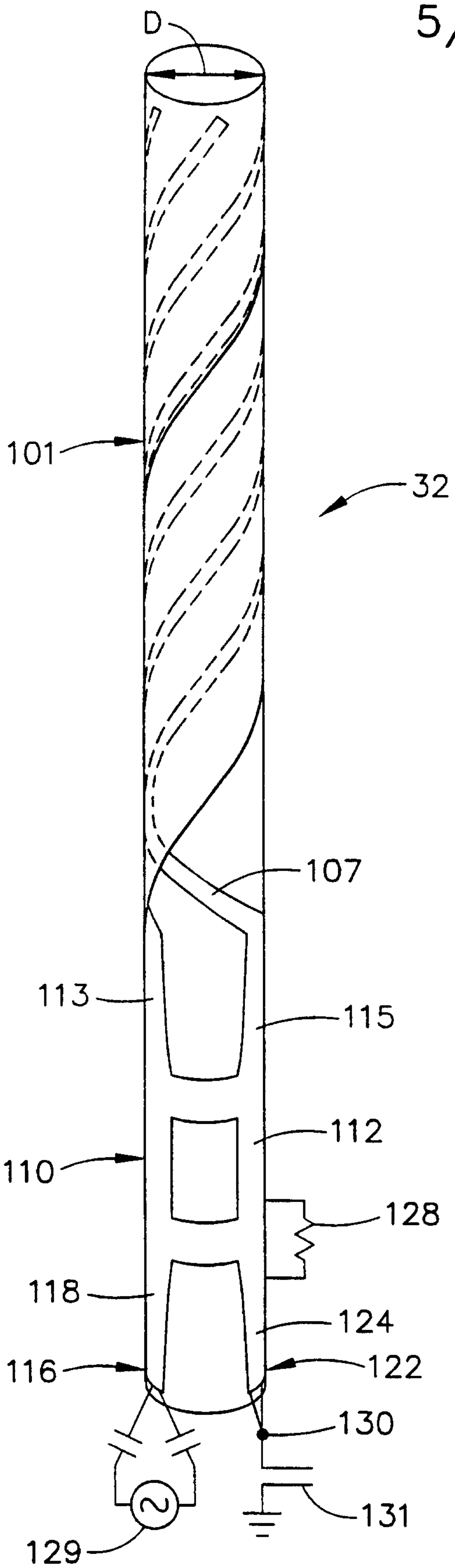

D
101
32
107
113
115
110
112
128
118
124
116
122
130
131
129

FIG. 7

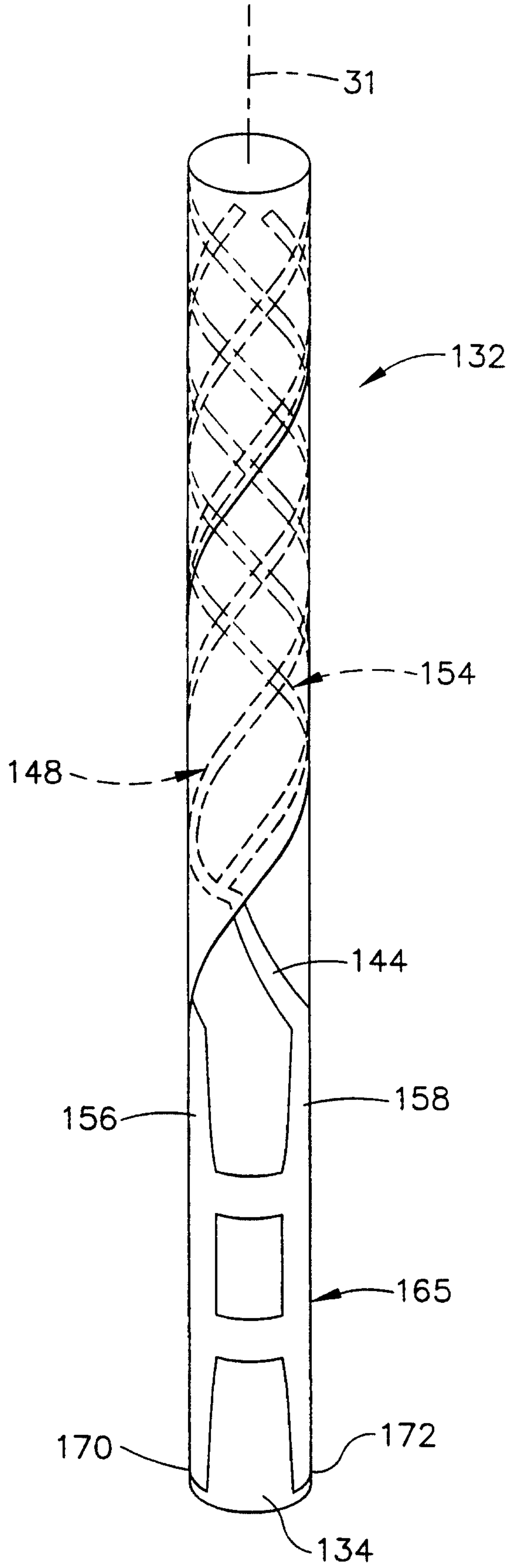

31
132
154
148
144
156
158
165
170
172
134

FIG. 10

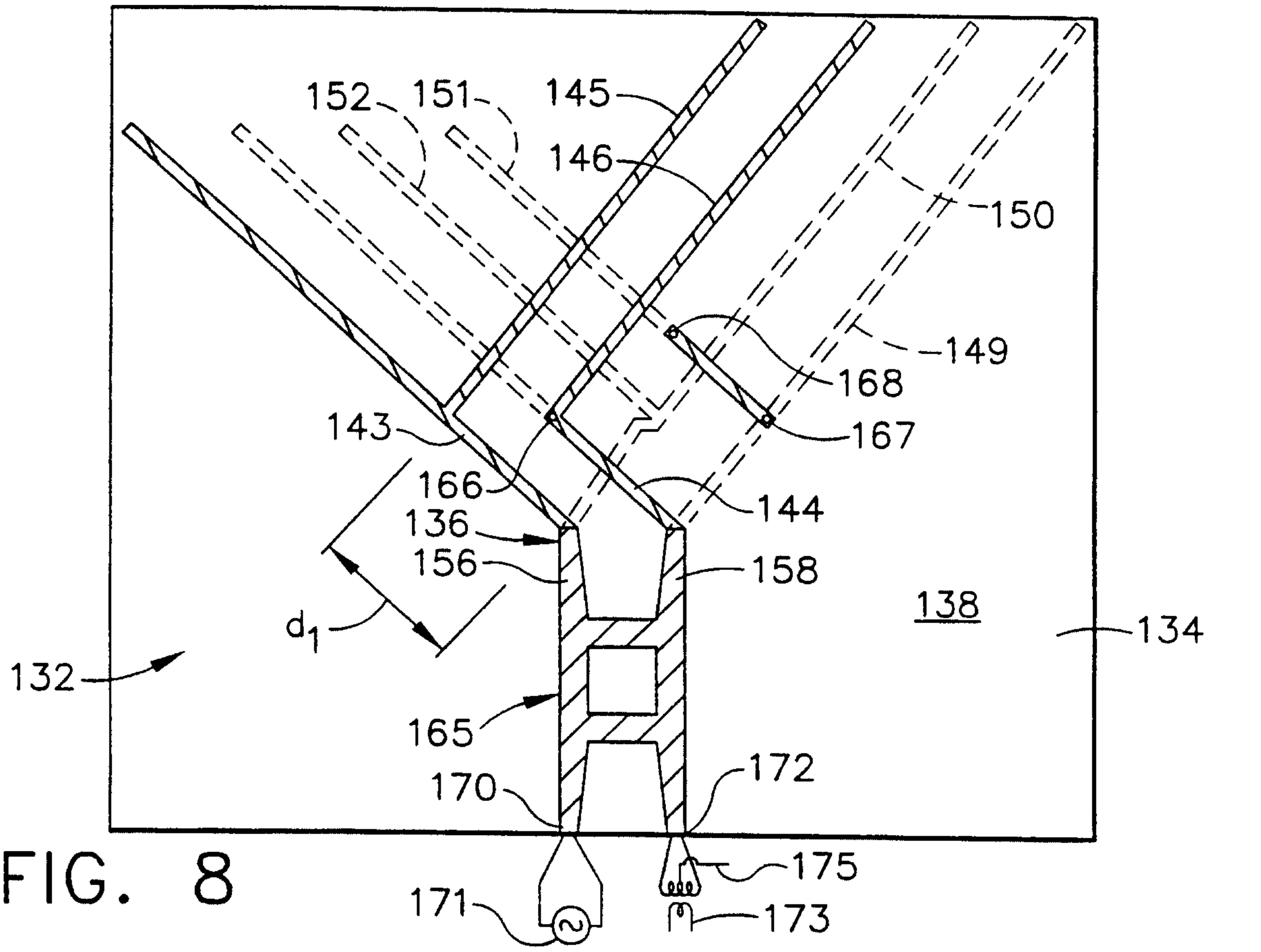

152
151
145
146
150
149
168
167
143
166
144
136
156
158
138
134
d1
132
165
170
172
175
171
173

FIG. 8

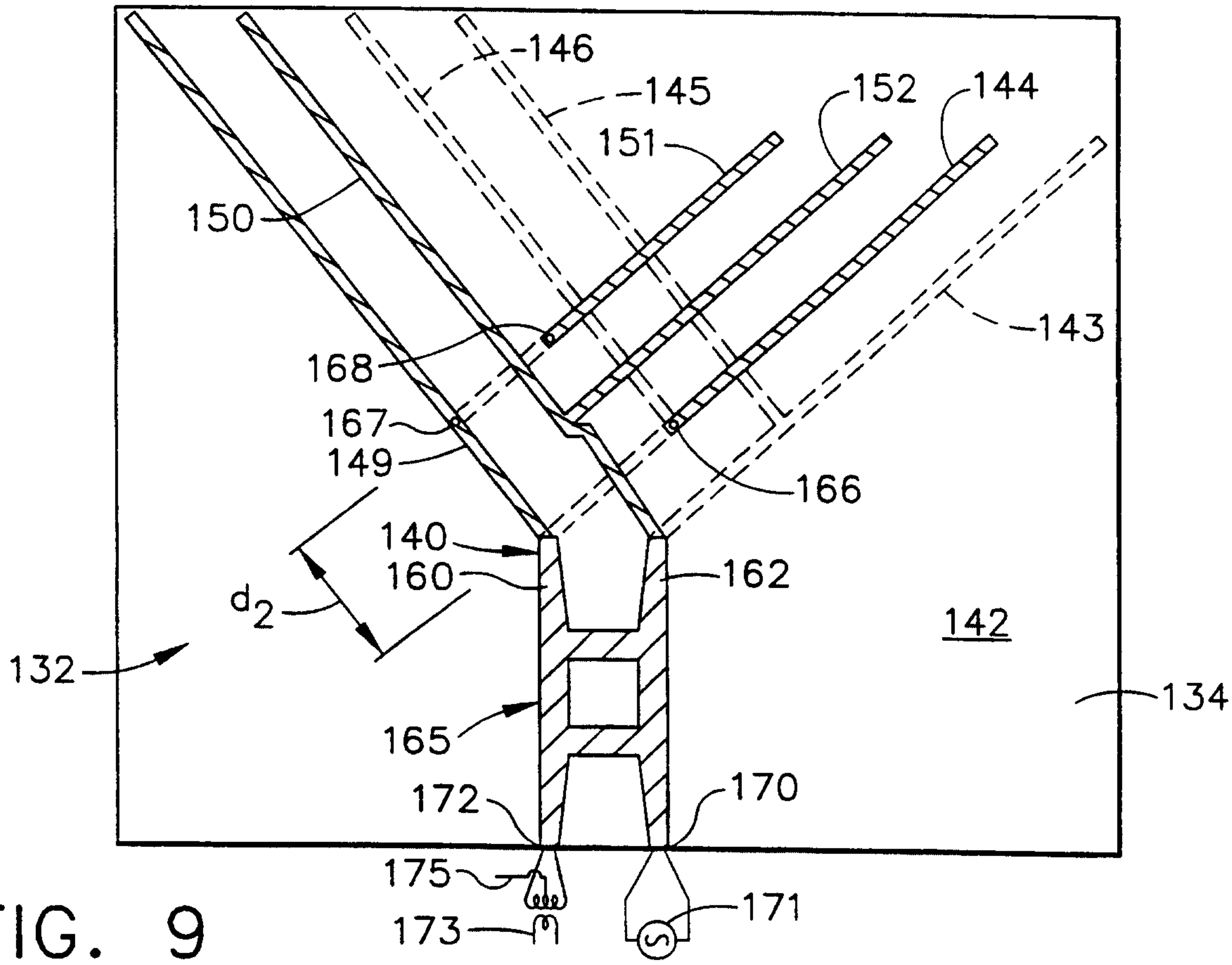

146
145
152
144
151
150
143
168
167
149
166
140
160
162
142
d2
132
134
165
172
170
175
171
173

FIG. 9