(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 May 2006 (11.05.2006)

PCT

(10) International Publication Number
WO 2006/050281 A2

(51) International Patent Classification: *H01Q 1/38* (2006.01)

(21) International Application Number: PCT/US2005/039302

(22) International Filing Date: 28 October 2005 (28.10.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/623,655 29 October 2004 (29.10.2004) US
11/254,432 20 October 2005 (20.10.2005) US

(71) Applicant *(for all designated States except US)*: SOUTHERN METHODIST UNIVERSITY [US/US]; Office of Legal Affairs, 6425 Boaz Lane, Room 205, Dallas, Texas 75275 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: LEE, Choon Sae [US/US]; 2936 Rosedale Ave., Dallas, Texas 75205 (US).

(74) Agent: MATSIL, Ira S.; Slater & Matsil, L.L.P., 17950 Preston Road, Suite 1000, Dallas, Texas 75252 (US).

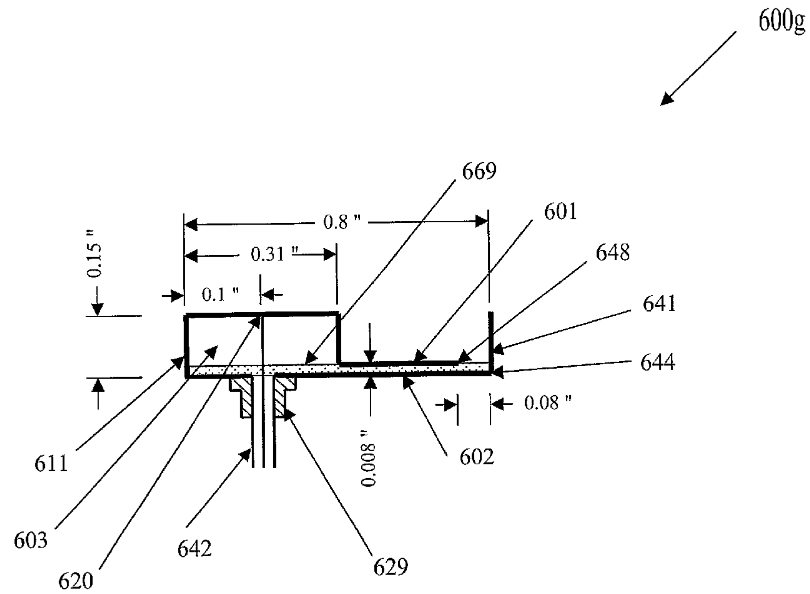
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHODS AND APPARATUS FOR IMPLEMENTATION OF AN ANTENNA FOR A WIRELESS COMMUNICATION DEVICE



(57) Abstract: A wireless communication device includes an antenna (600g) configured with two conductive elements (601/602) separated by an insulating medium (603). One conductive element (602) is a ground plane and the other is a microstrip line (601). The ground plane (602) is formed with a bend (644) proximate an end. The microstrip line and the ground plane exhibit a characteristic impedance that may vary along the length of the microstrip line. The separation distance of the microstrip line (601) from the ground plane (602) is changed to reduce the resonant frequency of the microstrip line.

WO 2006/050281 A2

METHODS AND APPARATUS FOR IMPLEMENTATION OF AN ANTENNA FOR A WIRELESS COMMUNICATION DEVICE

This application claims the benefit of U.S. Provisional Application No. 60/623,655, filed on October 29, 2004, entitled "Methods and Apparatus for Implementation of an Antenna for a Wireless Communication Device", and U.S. Non-Provisional Application No. 11/254,432 entitled "Methods and Apparatus for Implementation of an Antenna for a Wireless Communication Device", which applications are hereby incorporated by reference in its entirety.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application relates to commonly assigned patent applications, which are hereby incorporated herein by reference:

Patent or Serial No.	Filing Date	Issue Date	Attorney Docket No.
10/770,540	February 2, 2004		SMU-001
6,839,028	August 9, 2002	January 4, 2005	<xxx>

TECHNICAL FIELD

The present invention relates to methods and apparatus for providing a microstrip antenna of compact size such as may be used in wireless communication devices and the like.

BACKGROUND

The widespread use of cellular telephones and other compact or portable RF communication devices such as toll-tag readers, identification card readers, and devices for scanning items in inventory has resulted in intense interest in employing antennas with high efficiency and compact size. The early implementations of mobile cellular telephony devices were of lunchbox size or larger, and required a power level that generally required a substantial power source such as provided by an automotive alternator and battery. However, as cellular technology has evolved with paralleling reductions in size and power requirements, cellular telephones and other portable communication devices have become small enough to fit easily into the palm of one's hand, and can be operated for practical periods of time from a small internal rechargeable battery. Similarly, scanners for recognizing tagged items in inventory have become very compact and portable.

Over the years of development of radio and related telecommunication technologies, numerous antenna configurations have been developed. An antenna is a circuit element configured to convert RF (radio frequency) energy flowing in circuit conductors into a radiated form that can propagate freely in space. An antenna exhibits reciprocal properties in that the same physical configuration can receive as well as transmit radiation with substantially similar characteristics.

A basic antenna configuration is a dipole which is a conductive line, insulated at both ends, coupled to an RF power source near, but not necessarily at, its center. A monopole antenna is a variation of a dipole antenna that consists of half a dipole adjacent to a conductive plane configured to provide a mirrored electromagnetic field that functionally replaces the missing dipole half. An alternative to a dipole is a conductive loop of wire, also fed from an RF power source coupled to the wire ends.

Further variations of these antenna configurations include the addition of directive and reflective conductive elements that provide directivity to the radiated signal from the antenna, parabolic conductive surfaces to focus the radiated beam, waveguide termination configurations, microstrip lines, and combinations of these approaches.

From a design perspective, an antenna is required to exhibit a number of characteristics to make it a practical circuit element for use with a communication device. One characteristic is that it exhibits reasonable "gain", which relates to its radiation directivity and efficiency. Directivity refers to the directional variation of its transmitting and receiving properties. Relatively omnidirectional transmitting and receiving characteristics are often desired for portable communication devices, which avoid the need for the user to maintain an orientation of the device in a particular direction while communicating. Small dipole and loop antennas inherently exhibit substantially omnidirectional transmitting and receiving characteristics.

Efficiency refers to the fraction of power that is radiated compared to the total power delivered to the antenna, a portion of which is lost in the resistance of conductive elements and dielectric media. The need for high efficiency is related to the use of smaller batteries and smaller power processing circuit elements, since the amount of RF power that would otherwise have to be generated can be reduced. Efficiency is important because batteries make a significant cost and size contribution to the design of cellular telephones.

Another property of interest is the antenna input impedance. This refers to the ratio of voltage to current, including any phase difference that is applied to the terminals of the antenna, and affects possible need for additional circuit components that would otherwise be included for efficient coupling of power to the antenna. Antenna bandwidth refers to the variation of any property over a range of frequencies, and is an indication of the antenna's utility for a particular band of frequencies that may be allocated for its intended use. Antenna bandwidth is an important characteristic of antennas intended for use in portable communication devices because the assigned frequency bands may often have a bandwidth that is 6% – 8% or more of the nominal transmission frequency. Antenna bandwidth is particularly important for antennas that are small in relation to their wavelength because of the generally low efficiency of such relatively small antennas.

As the size of cellular telephones has been reduced, the size of the antenna has also been reduced. Early cellular telephones utilized a monopole antenna about a quarter wavelength in length, which was often retractable within the body of the communication device when not in use. Since the present frequency bands for cellular communication are at about 1 and 2 GHz, the corresponding length of an extended monopole antenna is about 3.2 or 1.6 inches, respectively. This has been a practical arrangement for some early portable telephones, but the continuing pressures of the marketplace provide advantage to products with antennas of even smaller size.

Microstrip antennas, which consist of a conductive strip on an insulating substrate applied over a conductive surface, have been an important step in reducing antenna size because of the absence of a mechanical structure projecting from the end of the telephone, such as a monopole antenna. A microstrip antenna can effectively be a layered structure on a surface of the telephone requiring little volume without compromising good transmitting and receiving performance. Nonetheless, the length of the conductive layer has been required to be on the order of a quarter wavelength in order to achieve reasonable antenna performance as measured by input impedance, antenna gain, bandwidth, or other parameter required by the design. Microstrip length has become a limitation as cellular telephones continue to shrink. In general, most antennas exhibit a compromise in performance when their size is substantially smaller than a quarter wavelength of the transmitted or received signal.

Telephones incorporating monopole and microstrip antennas are described in U.S. Patents 6,633,262 (Shoji, et al.), 6,628,241 (Fukushima, et al.), 6,281,847 (Lee), and 6,133,878 (Lee), which are incorporated herein by reference.

With widespread utilization of cellular telephones, a new characteristic, specific absorption rate (SAR) has become a parameter of great importance. SAR refers to the power absorbed in adjacent tissues of the head during transmitting operation of a cellular telephone. SAR represents a perceived risk for long-term exposure of head tissues as a consequence of the deep penetration of RF radiation in tissues of biological origin at frequencies used for cellular communication. Thus, it is desirable that SAR be reduced as much as possible. SAR is already a characteristic that is limited for cellular devices sold in certain countries such as Japan and Korea, and SAR may also become limited in devices sold in the U.S. As general uses for compact and portable transmitters become widespread, personally absorbed radiation will become an issue of greater interest and concern.

Design directions that can be taken to limit SAR are reduction in transmitted power, which is undesirable because it limits the useful range of the telephone or other transmitting device, locating the antenna farther from a person's head or other body part so as to reduce personal exposure to RF energy, which raises marketability issues for cellular telephone and other portable or compact products, increasing antenna efficiency so that less power is required to operate the telephone or other communication device, which is presently a design challenge for small antennas, and possibly altering the configuration of the antenna and its adjacent structures to reduce strength of the near-field radiation adjacent the user's head or other body part without adversely affecting the antenna radiation pattern or other antenna attributes such as antenna gain, size, or input impedance.

There has been extensive research to make microstrip antennas more suitable for use particularly as cellular telephone antennas, mainly because the conducting ground plane may partially shield electromagnetic radiation of the near-field area on the backside of the ground plane, where a user's head is likely to be located. As the size of the ground plane is reduced, its effectiveness at reducing the near field on the second side of the ground plane is correspondingly reduced. A popular technique for size reduction of microstrip antennas is to use thin vertical conductors connecting the radiating patch and the ground plane as in a PIFA (planar inverted F-antenna). However, as indicated above, antenna size has not been reduced beyond a certain level without compromising antenna performance. In many practical applications, as in cellular telephones, such limited size reduction may not be sufficient.

Accordingly, there are needs in the art for new methods and apparatus for configuring an antenna that is usable with portable or compact communication equipment, that can be configured in sizes significantly less than a quarter wavelength, yet preserve electrical characteristics of longer antennas such as input impedance, gain, and efficiency. Such antennas must be operable over frequency ranges that may extend to 6% - 8% or more in bandwidth. In addition, the new antenna configuration should exhibit reduced SAR for absorption of electromagnetic energy in adjacent tissues of the head or in proximate surrounding surfaces that are likely to be exposed during intended operation of the device.

SUMMARY

In accordance with one or more aspects of the present invention, a wireless communication device may include an antenna with at least two conductive elements separated by an insulating medium. The antenna is configured as a microstrip line that is a conductive strip with a characteristic impedance that may vary along the length of the strip. The separation distance of the conductive elements is changed at at least one location along the microstrip line so as to produce a corresponding change in the characteristic impedance of the microstrip line. This change in conductive element separation distance, which may or may not be abrupt, produces an electrical resonant frequency of the antenna that is lower than the resonant frequency of an antenna of the same length configured with a uniform conductive element separation distance.

In one embodiment, one of said conductive elements is preferably configured as a ground plane, and the other said conductive element is configured as a microstrip line separated from said ground plane by the insulating medium.

In one embodiment, the change in separation distance of the conductive elements is configured to be abrupt, producing an abrupt change in the local characteristic impedance of the microstrip line. In a further embodiment, the conductive strip is insulated from the ground plane except at a point. Preferably, the conductive strip is shorted to the ground plane at one end, and the other end of the conductive strip is left open.

In one embodiment, the ground plane is formed with a bend proximate an edge. Preferably, the bend is an angular bend. In a further embodiment, the bend in the ground plane is at substantially a right angle. In a further embodiment, the ground plane is bent at an angle that is greater than or less than a right angle. In a further embodiment, the bend is formed along a substantially straight line. In a further embodiment, a gap is formed between the end of the other said conductive element and the bend in the ground plane.

In one embodiment, the length of an antenna, configured as a microstrip line with at least one change in conductive element separation distance, is shorter than an antenna with uniform conductive element separation distance. Antennas that radiate with high efficiency are generally configured with lengths corresponding roughly to a quarter wavelength of the signal to be transmitted or received with one end open and one end shorted to a ground reference, or a half wavelength, with both ends open. Antennas can be configured with shorter lengths compared to a quarter or half wavelength, but antenna efficiency, as measured by a ratio of radiated power to the total power supplied to its terminals, ordinarily rapidly declines for antenna lengths substantially shorter than a quarter wavelength. This rapid deterioration of antenna performance for short antennas may be avoided by the invention herein disclosed.

In one further embodiment, the antenna is configured as a microstrip line with at least two conductive elements separated by an insulating medium, wherein one conductive element is configured as a ground plane with a first side and a second side and at least one edge, and the other conductive element is configured as a first microstrip line above said first side. In one embodiment the ground plane includes a bend proximate an edge. Preferably, the bend is an angular bend. The antenna preferably includes a third conductive element, with a first end and a second end, configured as a second microstrip line above said second side with an effective electrical length that is an odd multiple of about a quarter wavelength. Preferably, the third conductive element has an effective electrical length that is about a quarter wavelength. In one embodiment, the third conductive element may also include a bend with a portion that lies proximate the bent portion of the ground plane. Preferably, the bend in the third conductive element

is an angular bend. Antennas of multiple wavelengths may radiate, but are less useful in certain applications because of their large size and low efficiency. One end of the strip forming the second microstrip line preferably is open and configured to lie proximate an edge of said ground plane, and the other end of the second microstrip line is shorted to the ground plane. The third conductive element is configured as a second microstrip line above the second side of the ground plane with a characteristic impedance that may vary along the length of the second microstrip line. Accordingly, recognizing the general impedance inverting characteristics of a quarter wavelength transmission line, the second microstrip line can be configured with a length that is operative to obstruct currents on the first side of the ground plane from flowing over the edge of the ground plane onto the second side of the ground plane.

In a further embodiment, the second microstrip line is separated from the second side of the ground plane with at least one change in said separation distance. A change in separation distance at at least one location along the microstrip line, and which may be abrupt, is operative to cause a resonant frequency of the second microstrip line to be lower than a microstrip line with uniform separation distance from a ground plane. Accordingly, the length of said second microstrip line, which may include a bent portion, can be substantially shorter than a microstrip line with a uniform separation distance from a ground plane. Preferably, the bent portion is proximate an edge. Preferably, for efficient antenna operation, at least two changes in said separation distance of the second microstrip line from the ground plane are desired.

In accordance with one or more further aspects of the present invention, the change in said separation distance of said second microstrip line from the ground plane is abrupt.

In accordance with one or more further aspects of the present invention, the second microstrip line is configured with a curved end and the ground plane is configured with a curved edge. The curved end of the second microstrip line preferably is open and configured to lie proximate the curved edge of said ground plane. In a further embodiment, the ground plane may include a bent portion along a curved edge. The second microstrip line may include a bent portion wherein the bend is formed along the curved edge. Preferably, the bend is an angular bend. The other end of the second microstrip line is shorted to the ground plane. The second microstrip line thus can be configured to be operative to obstruct currents on the first side of the ground plane from flowing over the curved edge of the ground plane onto the second side of the ground plane.

In accordance with one or more further aspects of the present invention, a lossy magnetic medium may be applied over all or portions of the second side of the ground plane and over all or portions of the second microstrip line. The lossy magnetic medium can provide a mechanism to absorb radiated near fields that are a result of RF current that flows from the first side of the ground plane over an edge onto the second side of the ground plane, thereby reducing SAR.

In accordance with one or more further aspects of the present invention, a microstrip antenna is configured to lie above two sides of a ground plane by extending its conductive surface around an edge of the ground plane and remaining insulated from the edge.

In accordance with one or more further aspects of the present invention, a method includes configuring an antenna for a wireless communication device with at least two conductive elements, separating the conductive elements by an insulating medium, providing thereby a microstrip line with a characteristic impedance that may vary along its length. The separation distance of the conductive elements may be changed abruptly or more gradually at at least one location along the microstrip transmission line so as to produce a corresponding change in the microstrip line characteristic impedance. This change in conductor spacing produces an electrical resonant frequency of the antenna that is lower than the resonant frequency of an antenna of the same length configured with a uniform conductive element separation distance from a ground plane. Preferably, for efficient antenna operation, at least two changes in the separation distance are desired.

In accordance with one or more further aspects of the present invention, a method includes configuring an antenna for a wireless communication device with at least two conductive elements, separating the conductive elements by an insulating medium, providing thereby a microstrip line with a characteristic impedance that may vary along its length, and forming one conductive element as a ground plane with a bend proximate an edge. Preferably, the method includes forming the bend as an angular bend. In a further embodiment, the method includes forming the bend in the ground plane at substantially a right angle. In a further embodiment, the method includes forming the bend in the ground plane at an angle that is greater than or less than a right angle. In a further embodiment, the method includes forming the bend along a substantially straight line. In a further embodiment, the method includes forming a gap between the end of the other conductive element and the bend in the ground plane.

In accordance with one or more further aspects of the present invention, a method includes configuring an antenna with at least two conductive elements separated by an insulating medium, configuring one conductive element as a ground plane with a first side and a second side and at least one edge, and configuring the other conductive element as a first microstrip line above the first side with an insulating substrate therebetweeen. The method preferably includes configuring a third conductive element with a first end and a second end as a second microstrip line above the second side with an effective length that is an odd multiple of a quarter wavelength. The method preferably includes configuring the third conductive element with an effective length that is a quarter wavelength. A first end of the second microstrip line is preferably open and proximate an edge of the ground plane and the second end of the second microstrip line is shorted to the ground plane, so as to obstruct currents on the first side of the ground plane from flowing over the edge of the ground plane onto the second side of the ground plane. In one embodiment, the method includes forming a bend in the ground plane proximate an edge. In a further embodiment, the method includes forming a bend in the third conductive element proximate an edge. Preferably, the method includes forming the bend in the third conductive element as an angular bend. In a further embodiment, the method includes forming a bend in the third conductive element proximate an edge at an angle that is substantially a right angle. In a further embodiment, the method includes forming a bend in the third conductive element proximate an edge at an angle that is substantially greater than or less than a right angle.

In accordance with one or more further aspects of the present invention, a method includes configuring the separation distance of the conductive elements of the second microstrip line with abrupt or more gradual changes in the separation distance at at least one location along the second microstrip transmission line so that it can be configured with a length that is shorter than a microstrip transmission line with uniform conductive element separation distance. Preferably, for efficient antenna operation, at least two changes in the separation distance are desired.

In accordance with one or more further aspects of the present invention, a method includes applying a lossy magnetic medium over all or portions of the second side of the ground plane and over all or portions of the second microstrip line, so as to provide a mechanism to absorb radiated near fields that are a result of RF current that flows from the first side of the ground plane over an edge onto the second side of the ground plane, thereby reducing SAR.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates a monopole antenna of the prior art;

FIG. 2 illustrates a microstrip antenna with discontinuities in width;

FIGs. 3a-3d illustrate microstrip antennas in accordance with one or more aspects of the present invention;

FIGs. 4a - 4c illustrate microstrip antennas in accordance with one or more aspects of the present invention;

FIGs. 5a and 5b illustrate microstrip antennas with a second conductive strip configured to reduce currents on the second side of the ground plane in accordance with one or more aspects of the present invention;

FIG. 6a illustrates a microstrip antenna with second and third conductive strips configured to reduce currents on the second side of the ground plane in accordance with one or more aspects of the present invention;

FIG. 6b illustrates a microstrip antenna with a second conductive strip on the second side of a ground plane configured to reduce currents in accordance with one or more aspects of the present invention;

FIG. 6c illustrates a microstrip antenna with second and third conductive strips on the second side of a ground plane configured to reduce currents in accordance with one or more aspects of the present invention;

FIG. 6d illustrates a microstrip antenna in accordance with one or more aspects of the present invention;

FIG. 6e illustrates a microstrip antenna in accordance with one or more aspects of the present invention;

FIG. 6f illustrates a three-dimensional and an edge view of a circular conductive strip configured to reduce currents on the second side of the ground plane in accordance with one or more aspects of the present invention;

FIG. 6g illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a bend in the ground plane proximate an edge;

FIG. 6h illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a bend in the ground plane proximate an edge followed by a second bend in the ground plane to form a ground plane segment over a segment of a conductive radiating strip;

FIG. 6i illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a bend in the ground plane proximate an edge, and a third conductive element with changes in separation distance from the ground plane and including a bend proximate an edge;

FIG. 6j illustrates a microstrip antenna in accordance with one or more aspects of the present invention including a ground plane with a bend proximate an edge, and a third conductive element with one change in separation distance from the ground plane and including a bend proximate an edge;

FIG. 6k illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a bend with an angle greater than a right angle in the ground plane proximate an edge;

FIG. 6ℓ illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a bend with an angle greater than a right angle in the ground plane proximate an edge, and a third conductive element with changes in separation distance from the ground plane and including a similar bend proximate an edge;

FIG. 6m illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a ground plane with a bend with an angle greater than a right angle proximate an edge, and a third conductive element with one change in separation distance from the ground plane and including a similar bend proximate an edge;

FIG. 6n illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a bend in the ground plane proximate an edge and a conductive element with a hollow or filled portion and a sloping surface;

FIG. 6o illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a conductive ground plane with a bend proximate an edge, a conductive element with a hollow or filled portion and a sloping surface, and a third conductive element with changes in separation distance from the ground plane and including a bend proximate an edge;

FIG. 6p illustrates a microstrip antenna in accordance with one or more aspects of the present invention, including a conductive ground plane with a bend proximate an edge, a conductive element with a hollow or filled portion and a sloping surface, and a third conductive element with one change in separation distance from the ground plane and including a bend proximate an edge;

FIG. 7 illustrates a block diagram of a cellular telephone in accordance with one or more aspects of the present invention; and

FIG. 8 illustrates a sketch of a cellular telephone set, including a circular conductive strip configured to reduce currents on the second side of a ground plane in accordance with one or more aspects of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the presently preferred embodiments are discussed in detail below. It should be appreciated, however, that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

Reference is now made to the drawings, wherein like designations indicate like elements, as well as numerals ending in the same last two digits. Referring initially to FIG. 1, a monopole antenna 100 of the prior art is illustrated. The monopole antenna 100 includes a conductive wire 101 extending above a ground plane 102. The monopole antenna is fed through an aperture 125 in the ground plane 102 from a feed point 120 by an RF power source (not shown). The monopole antenna 100 extends a distance L above the ground plane 102, typically about a quarter wavelength at the transmitting or receiving frequency. The ground plane 102 has a width W that is generally on the order of half a wavelength or more.

An RF current 173 in the conductive wire 101 induces a flow of charge on the topside of the ground plane 102, producing at least partially a mirror image on the ground plane 102 of the current in the conductive wire 101. The mirrored current creates the effect of a dipole antenna of length 2L. Ideally the width of the ground plane W is much longer than the wavelength of the radiated signal, but in practice the width W may be comparable to or shorter than a wavelength.

Current 174 induced on the topside of the ground plane 102 by the RF current 173 in conductive wire 101 encounters a discontinuity in conductivity at the edge of the ground plane 102. The result is to induce a current 175 that flows over the edge of the ground plane 102, and a corresponding current 176 that flows on the backside of the ground plane 102.

Ordinarily the ground plane 102 would be expected to provide a shielding effect for electromagnetic fields induced by the conductive wire 101 for the region facing the backside of the ground plane 102. However, as a consequence of its limited length W and limited dimension in the cross direction, currents induced on the back side of the ground plane 102 as described above, act as a radiating source for near fields to the region facing the back side of the ground plane 102.

If such an antenna arrangement were placed adjacent to a person's head, a substantial electromagnetic near field would be coupled thereto by backside currents such as RF current 176. Thus, disadvantages of this prior art antenna include the substantial length required for a conductive radiating wire extending above a ground plane 102, and the substantial electromagnetic near fields that are created on the backside of the antenna system.

Turning now to FIG. 2 illustrated is a microstrip antenna 200 described in co-pending patent application Serial No. 10/214,746, filed August 9, 2002, and incorporated herein by reference. The microstrip antenna 200 includes a conductive radiating strip 201 that is separated from a ground plane 202 by an insulating substrate 203. The conductive radiating strip 201 is fed by an RF power source (not shown) at the feed point 220, which is preferably coupled off-center to the radiating microstrip 201 to obtain the required antenna impedance, and which might ordinarily be coupled to an RF power source on the back side of the ground plane 202 through an aperture 225 in the ground plane 202 in a manner that may be similar to the arrangement illustrated in FIG. 1. The center of the conductive radiating strip 201 is identified in FIG. 2 with the dashed line labeled "cl" (for center line). The coupling on the backside of the ground plane 202 to the feed point 220 may be made with a coaxial connector with a flange grounded to the ground plane (not shown).

The length L of the conductive radiating strip 201 would ordinarily be about or somewhat less than a half wavelength of the signal to be radiated. However, discontinuities in the width of the conductive radiating strip 201, illustrated in the figure by the unequal widths W1 and W2, provide corresponding discontinuities in the characteristic impedance of the strip line forming the radiating strip, producing an antenna with a length L substantially less than half a wavelength but with some properties of an antenna with a length much closer to a half wavelength.

To create substantial discontinuities in strip line characteristic impedance so as to accommodate a shorter length of the radiating strip 201, substantial differences in the widths W1 and W2 are used. A strip line with a width reasonably greater than the separation from the underlying ground plane 202 exhibits a characteristic impedance roughly proportional to the ratio of its separation distance from the ground plane 202 to its width. Substantial discontinuities in strip line width thus produce substantial discontinuities in characteristic impedance. These discontinuities result in long edges in the radiating strip 201 such as edges 233 and 234 illustrated on FIG. 2. The equivalent magnetic currents at the opening edges 231 and 232 of the conductive radiating strip 201 generally conduct current in directions opposite to those on edges 233 and 234, which make little net contribution to the radiated field while the conduction loss remains about the same. The field cancellation effect reduces the efficiency of this antenna configuration and results in limited opportunity to construct an antenna with short length compared to a half wavelength of the radiated signal without compromising antenna performance.

Turning now to FIG. 3a, illustrated is an edge view of a microstrip antenna 300a with discontinuous separation distance of a conductive radiating strip 301 from a ground plane, constructed according to principles of the present invention. The microstrip antenna 300a includes a conductive radiating strip in the form of a microstrip line, which has an effective electrical length of about a half wavelength, with abruptly changed separation distance from a ground plane 302. The conductive radiating strip 301 is separated from the conductive ground plane 302 by an insulating substrate 303 with varying thickness such as provided by indentations (e.g., grooves) to accommodate the shape of the conductive radiating strip 301. It is contemplated that different or similar insulating materials may be used for the insulating substrate 303 and the dielectric material for the transmission line with this antenna (or with any of the antennas described hereinbelow). The conductive strip 301 is fed from an RF power source (not shown) by a conductor at a feed point 320 to the radiating microstrip 301 through an aperture 325 in the ground plane 302 and the insulating substrate 303. As described above with reference to FIG. 2, the feed point 320 is preferably coupled off-center to match the input impedance. A coaxial connector 329 with a flange coupled to the ground plane 302 may be used to provide low-loss coupling to the feed point 320. Although the antenna 300a includes a coaxial transmission line coupled to the radiating element 301 with a coaxial connector 329, it is contemplated that other transmission line types can also be used with this antenna (or with any of the antennas described hereinbelow) such as "twin lead" (parallel conductor line), using any suitable interconnecting arrangement.

As an example of discontinuous separation distance of a radiating strip above a ground plane, separations of 0.008 inch and 0.25 inch are shown on FIG. 3a. The smaller separation distance preferably is as thin as possible in view of the requirements of the application, and the larger separation distance preferably is about 0.5% to about 5% of a wavelength. If the larger separation distance is made thicker, the antenna bandwidth is wider and the antenna efficiency is better. These changes in separation distance from the ground plane 302 with a substantial ratio provide roughly proportionate changes in the impedance of the strip line formed by the conducting strip 301and the ground plane 302. The antennas contemplated herein may include abrupt and/or more gradual changes in the separation distance of a radiating element and/or the separation distance of any additional conductive element that may be included in the design to alter a radiation field or other operating characteristic.

As indicated above, characteristic impedance of a strip line varies proportionately as the separation distance of the strip line from the ground plane. Thus, substantial changes in characteristic impedance are able to be achieved without introducing long conducting paths with opposing and canceling radiated fields and incurring significant power loss. The result is a microstrip antenna with an overall length L that can be substantially shorter than the length of a microstrip antenna constructed with a uniform separation distance from a ground plane, but without compromises in antenna performance. Including two or more changes in separation distance from the ground plane, the length L can practically be less than one quarter that of a microstrip antenna configured without changes in separation distance.

Turning now to FIG. 3b, illustrated is an edge view of a microstrip antenna 300b, which has an effective electrical length of about a quarter wavelength, with discontinuous separation distance of a conductive radiating strip 301 from a ground plane 302, constructed according to principles of the present invention. Elements of the antenna 300b on FIG. 3b that are similar to elements on FIG. 3a will not be discussed. The conductive radiating strip 301 illustrated on FIG. 3a has an effective electrical length of about a half wavelength and is shown with both ends open. The conductive radiating strip 301 illustrated on FIG. 3b has an effective electrical length of about a quarter wavelength and has one end open and one end shorted to the ground plane 302 with shorting strip 311.

For the two-step, microstrip design illustrated on FIG. 3b with an equivalent electrical length of a quarter wavelength, microstrip section lengths of about 0.75 cm., 1 cm., and 0.75 cm. (for a total microstrip length of 2.5 cm.) result in an electrical resonant frequency of about 700 MHz when the dielectric material has a permittivity of about 1.0. The resonant (quarter wavelength) length of a microstrip line antenna 300b without changes in separation distance at this frequency is about 10.5 cm. The gain of this antenna in a preferred direction was measured to be about 0 – 2 dBi, i.e., 0 – 2 dB greater than a reference isotropic radiator.

Turning now to FIG. 3c, illustrated is an edge view of a microstrip antenna 300c with discontinuous separation distance of a conductive radiating strip 301 from a ground plane 302, constructed according to principles of the present invention. The embodiment of FIG. 3c (and of FIG. 3d as described below) has an advantage over the embodiments of FIGs. 3a and 3b in that it will have a higher efficiency, although at the expense of size. This embodiment might be useful in applications where size is less critical, e.g., with RF tags used to track large items.

Elements of the antenna on FIG. 3c that are similar to elements on FIG. 3a will not be discussed. The conductive radiating strip 301 in this illustrative example has an effective electrical length of about a half wavelength, and is shown with two changes in separation distance from the ground plane at locations 358 and 359. In this example, the feed point 320 is at a small separation distance from the ground plane, and the ends of the conductive radiating strip 301 are at a large separation distance. The location of the feed point 320 is preferably offset from the center of the radiating strip 301 as previously discussed to provide the necessary feed-point impedance to match that of the RF power source. A coaxial connector 329 with a flange coupled to the ground plane 302 may be used to provide low-loss coupling to the feed point 320.

The microstrip line 301 and the ground plane 302 are preferably fabricated of a material such as copper, aluminum, silver, or other material or alloy with suitably good conductive properties, with a conductive material thickness typically on the order of 1 mil. The insulating substrate 303 is preferably fabricated of a mechanically stable dielectric but preferably with a low relative dielectric constant near 1.0 such as foam, e.g., such as Rohacell 51HF, available from Richmond Aircraft Products, 13503 Pumice St., Norwalk, CA. Using a dielectric material with a high dielectric constant reduces the antenna size further but results in an antenna with lower efficiency. General manufacturing techniques including additive and subtractive lithographic processes for forming multi-layer structures of conductive and insulating materials are well known in the art and will not be described in the interest of brevity.

Turning now to FIG. 3d, illustrated is an edge view of a microstrip antenna 300d with changes in separation distance above a ground plane 302, constructed according to principles of the present invention. The conductive radiating strip 301 illustrated on FIG. 3d has an effective electrical length of about a quarter wavelength and has one end open and one end shorted to the ground plane 302 with shorting strip 311. The remaining elements of the antenna on FIG. 3d that are similar to elements on FIGs. 3a and 3b will not be discussed in the interest of brevity.

Turning now to FIG. 4a, illustrated is an edge view of a microstrip antenna 400a with changes in separation distance such as 458 and 459 above a ground plane 402, constructed according to principles of the present invention. Unlike the microstrip antenna illustrated on FIG. 3a the antenna illustrated on FIG. 4a has an even top surface 401, which may have advantages in manufacturing an end product. In this case, any useful and appropriate material for fabrication convenience can be used to fill the cavities. In addition, the interior portion of the conductive element between the locations of the changes in separation distance 458 and 459 may be left hollow or filled with a nonconductive material. The other elements illustrated on FIG. 4a correspond to similar elements shown on FIG. 3a and will not be discussed in the interest of brevity, and the electrical performance of the antenna illustrated on FIG. 4a is substantially similar to that for the antenna illustrated on FIG. 3a. This fill modification can be made to any of the embodiments disclosed herein.

Turning now to FIG. 4b, illustrated is an edge view of a microstrip antenna 400b with changes in separation distance 458 and 459 above a ground plane 402, with an even top surface 401, constructed according to principles of the present invention. Similar to the antenna illustrated in FIG. 4a, the interior portion of the conductive element between the locations of the changes in separation distance 458 and 459 may be left hollow or filled with a nonconductive material. The effective electrical length of the microstrip antenna 400b is about a quarter wavelength. The shorting strip 411 shorts the right end of the microstrip antenna 400b to the ground plane 402. The other elements illustrated on FIG. 4b correspond to similar elements shown on FIG. 4a and will not be discussed in the interest of brevity.

Turning now to FIG. 4c, illustrated is an edge view of a microstrip antenna 400c configured with an electromagnetically transparent enclosure 437 such as a plastic or other dielectric material, on whose internal or external surfaces are disposed the conductive elements of the antenna, constructed according to principles of the present invention. Preferably, the enclosure is hermetically sealed to prevent ingress of water vapor and other contaminants. The container may contain a solid dielectric material such as Teflon® or other suitable insulator, or it may contain a dielectric foam, or a gas such as dry nitrogen, or even a vacuum. The other elements illustrated on FIG. 4c correspond to similar elements shown on FIG. 4a and will not be discussed in the interest of brevity. Any of the other antenna configurations illustrated herein may also be configured with an electromagnetically transparent enclosure.

Turning now to FIG. 5a, illustrated is an edge view of a microstrip antenna 500a with changes in separation distance above a ground plane, constructed according to principles of the present invention. The microstrip antenna includes a second conductive strip 510 formed as a microstrip line on the back side of the ground plane 502 with its left end 511 shorted to the ground plane 502 and its right end 512 electrically open and proximate the edge 523 of the ground plane 502. The length L of the second conductive strip 510 is preferably configured to be about a quarter of a wavelength for the signal to be transmitted, but odd multiples of about a quarter wavelength can also be used.

The second conductive strip 510 is operative as a quarter wavelength transformer, providing very large impedance at the open end. Thus, when a finite voltage is applied at the open end, the current that flows is very small.

Currents ordinarily conducted around the right edge 523 encounter an open circuit at the frequency of the signal to be transmitted, and are reflected back onto the top side 522 of the ground plane 502. These currents beneficially do not appear on the backside of the assembly, and thereby do not contribute to near-field electromagnetic radiation that might otherwise be coupled to a person's head. Similarly, a third conductive strip can be located at another edge of the ground plane 502 to reflect currents ordinarily flowing toward that another edge. The current-reflecting operation of the second or third conductive strip does not depend on the discontinuous separation distance property of the conductive radiating strip 501, and can thus also be used with an ordinary microstrip antenna constructed without changes in separation distance from a ground plane. However, the length of a conductive strip without changes in separation distance will be substantially longer than one with changes.

Turning now to FIG. 5b, illustrated is an edge view of a microstrip antenna 500b with changes in separation distance above a ground plane, and a shorting strip 511 shorting the right end of the radiating strip 501 to the ground plane 502, constructed according to principles of the present invention. The microstrip antenna 500b, which has an effective electrical length of about a quarter wavelength, includes a second conductive strip 510 configured as a microstrip line on the back side of the ground plane 502 with one end 511a shorted to the ground plane and its other end 512 electrically open and proximate the edge 523 of the ground plane. In addition, a third conductive strip 510a is configured as a microstrip line on the back side of the ground plane 502 with one end coupled near the shorted end of the second conductive strip 510 and its other end 512a electrically open. Both conductive strips 510 and 510a are operative to obstruct flow of RF currents on the backside of the ground plane 502.

Turning now to FIG. 6a, illustrated is an edge view of a microstrip antenna 600a with changes in separation distance from a ground plane, constructed according to principles of the present invention. The microstrip antenna includes second and third conductive strips 610 and 610a, each with an effective electrical length of about a quarter wavelength on the second side of the ground plane 602 with one end, e.g., 611 shorted to the ground plane and its other end, e.g., 612 electrically open as described with reference to FIG. 5a and proximate an edge, e.g., 623 of the ground plane 602. The second and third conductive strips 610 and 610a are separated from the ground plane 602 by an insulating substrate, e.g., 603a.

The second conductive strip 610 is configured with changes in separation distance from the second side of the ground plane 602. The resulting changes in impedance of this strip line produce an effective electrical length that is substantially longer than its physical length. Thus, the second conductive strip 610 can be configured as a quarter wavelength transmission line with a length L that may be substantially shorter than a conductive strip with uniform separation distance from a ground plane 602, creating thereby an open circuit that can reflect RF currents ordinarily conducted around the right edge 623 of the ground plane 602 back onto the first side of the ground plane.

The RF current-reflecting property of the second conductive strip 610 does not depend on the discontinuous separation property of the conductive radiating strip 601, and can thus also be used with an ordinary microstrip antenna without changes in separation distance. In addition, a third conductive strip with changes in separation distance from the second side of the ground plane 602 can be located on another edge of the ground plane 602 to reflect currents ordinarily flowing toward that another edge.

FIG. 6a also illustrates a lossy magnetic layer 605 applied over the second side of the ground plane 602. The lossy magnetic layer may cover all or portions of the second side of the ground plane 602 and all or portions of a conductive strip 601 operative to reflect currents back onto the first side of the ground plane 602. The lossy magnetic layer 605 provides a mechanism to absorb near field radiation that might be induced on the backside of the ground plane 602 with only nominal effect on the radiated far field. Thus, SAR can be further reduced without substantially affecting the principal radiation characteristics of the antenna. Preferred exemplary materials with absorptive properties at frequencies used for cellular communication are lossy ferrite materials. Desirable properties of a lossy magnetic material are a large imaginary component of permeability at the transmitting frequency so as to provide an absorptive near-field loss mechanism, and low electrical conductivity. While illustrated exemplary with respect to the embodiment of FIG. 6a, it is understood that the lossy magnetic layer 605 can be utilized with any of the embodiments described herein.

FIG. 6b illustrates an edge view of a microstrip antenna 600b with discontinuous separation distance of a conductive radiating strip 601 from a ground plane 602, constructed according to principles of the present invention. The microstrip antenna 600b, which has an effective electrical length of about a quarter wavelength, includes a conductive radiating strip 601 in the form of a microstrip line with two abrupt changes in separation distance 658 and 659 from a ground plane 602. The conductive radiating strip 601 is separated from the conductive ground plane 602 by an insulating substrate 603 with varying thickness, such as would be provided by indentations (e.g., grooves) to accommodate the changes in separation distance of the conductive radiating strip 601. The conductive strip 601 is fed from an RF power source (not shown) by a conductor at a feed point 620 through an aperture 625 in the ground plane 602 preferably using a coaxial connector 629 with a flange coupled to the ground plane 602. The changes in separation distance from the ground plane 602 permit the microstrip antenna 600b to be constructed with an overall length L that can be substantially shorter than the length of a microstrip antenna constructed with a uniform separation distance from a ground plane, but without compromises in, and even improving on, antenna performance. Including the two changes in separation distance 658 and 659 from the ground plane 602, the length L can practically be less than one quarter that of a microstrip antenna configured without changes in separation distance.

The microstrip antenna 600b includes second and a third conductive strips 610 and 610a on the second side of the ground plane 602, separated from the conductive ground plane 602 by insulating substrate 603a with one end of conductive strip 610 shorted to the ground plane 602 with short 611a, and the other end of each (612 and 612a, respectively) electrically open as described with reference to FIG. 5b. The second and third conductive strips 610 and 610a are preferably configured as quarter wavelength transmission lines. The current-reflecting operation of the second and third conductive strips 610 and 610a do not depend on the discontinuous separation property of the conductive radiating strip 601, and could be used with an ordinary microstrip antenna without changes in separation distance. The second and third conductive strips 610 and 610a obstruct RF currents from flowing onto the backside of the ground plane 602 and thereby substantially reduce near-field radiation above the second side (back side) of the ground plane, i.e., on the side opposite the microstrip antenna. The microstrip antenna 600b preferably includes a lossy magnetic material 605 to further absorb near-field radiated energy on the backside of the ground plane 602.

Turning now to FIG. 6c, illustrated is a three-dimensional view of a microstrip antenna 600c with changes in separation distance from a ground plane, constructed according to principles of the present invention. The microstrip antenna, which has an effective electrical length of a half wavelength, includes a second conductive strip 610 on the second side of the ground plane 602 with its left end 611 shorted to the ground plane 602 and its right end 612 electrically open as described with reference to FIG. 5a and proximate the edge 623 of the ground plane 602. In addition, a third conductive strip 610a is included on the second side of the ground plane 602 with its right end 611a shorted to the ground plane 602 and its left end 612a electrically open. Both conductive strips 612 and 612a preferably include changes in separation distance, e.g., 658 and 659, from the ground plane as described with respect to the antennas illustrated hereinabove. The feed point 620 is offset from the center of the radiating strip 601 to provide the necessary feed-point impedance to match that of an RF power source. The center of the radiating strip 601 is illustrated with the dashed line cl. A coaxial connector (not shown) with a flange coupled to the ground plane 602 may be used to provide low-loss coupling to the feed point 620 through an aperture 625 in the ground plane 602.

Turning now to FIG. 6d, illustrated is an edge view of a microstrip antenna 600d with changes in separation distance from a ground plane 602, constructed according to principles of the present invention. The radiating conductive strip 601, which has an effective electrical length of a half wavelength, extends beyond the edges of the ground plane 602 and continues over the backside of the ground plane 602. In this manner, the length L can be further reduced as well as reducing the size of the ground plane 602. The radiating strip 601 preferably is fed from an off-center feed point 620 to provide the necessary feed-point impedance match. The feed point 620 preferably is coupled to an RF power source using a coaxial connector as illustrated, or, as previously indicated, any other feeding method such as a stripline feed. In the configuration illustrated on FIG. 6d, the shield of the coaxial cable is coupled to the radiating strip 601, and the center conductor of the coaxial cable is coupled to the ground plane 602.

Turning now to FIG. 6e, illustrated is an edge view of a microstrip antenna 600e with an equivalent electrical length of a quarter wavelength, with changes in separation distance from a ground plane 602, constructed according to principles of the present invention. The radiating conductive strip 601, which has an effective electrical length of a quarter wavelength, extends beyond the edges of the ground plane 602 and continues onto the back side of the ground plane 602 in the manner described with respect to FIG. 6d, above. In this manner, the length L of this quarter wavelength antenna can also be further reduced. The thickness of the insulating substrate 603a on the back side of the ground plane 602 is shown larger than the thickness of the insulating substrate 603 on the top side of the ground plane 602 so as to improve bandwidth and efficiency, which can be employed with other antenna configurations described herein. Again, as previously illustrated on FIG 6d, the shield of the coaxial cable is coupled to the radiating strip 601, and the center conductor of the coaxial cable is coupled to the ground plane 602.

Turning now to FIG. 6f, illustrated is a three-dimensional view and an end view 600f of a conductive strip 610 above a second side (back side) of a ground plane 602 constructed according to principles of the present invention. The conductive strip 610 is configured with a curved outer end 612 proximate the outer edge of the ground plane 602 and separated from the ground plane 602 by an insulating medium 603. The conductive strip 610 is further configured with changes in separation distance from the ground plane 602. The central point 611 of the conductive strip 610 is shorted to the ground plane 602 with a conducting pin. The conductive strip 610 can thus be configured as a quarter wavelength cylindrical transmission line. The current-obstructing effect of a quarter wavelength transmission line with one end shorted and one end open is described hereinabove, e.g., with reference to FIGs.5a and 6a. This produces a high impedance for RF current that might flow over the curved outer edge of the ground plane 602 onto the back side, as might be induced by an antenna on the opposing side. In this manner, the troublesome near-field radiation likely to be exposed to a person's head when using a cellular telephone can be substantially reduced. If the conductive strip 610 is fed off-center, the TM_{11} mode can be excited to obtain a radiation pattern similar to that of a dipole.

Turning now to FIG. 6g, illustrated is an edge view of a microstrip antenna 600g with a change in separation distance of a conductive radiating strip 601 from a folded ground plane 602, constructed according to principles of the present invention. A microstrip antenna with multiple changes in separation distance of a conductive radiating strip 601 from a ground plane 602 is in accordance with further aspects of the present invention. The dimensions illustrated for the antenna on FIGs. 6g through 6p are similar and are operative for transmitting and receiving frequencies of about 860 MHz. The dimension of the antenna out of the plane of the figure is about 0.4 inch. The conductive radiating strip 601 is separated from the ground plane 602 by an insulating substrate 603. A radiating field is effectively produced in the region above the edge 648 of the conductive radiating strip 601. The dielectric material forming the insulating substrate 603 has a dielectric constant of about 1.0 for the 860 MHz antenna illustrated. To form the small separation distance between the conductive radiating strip 601 and the folded ground plane 602, a thin dielectric layer 669 of Rogers RO 4003 material with dielectric constant about 3.38 can be formed under the insulating substrate 603. A separation distance of about 0.008 inch is illustrated in the figure, but an even thinner layer can result in an antenna with even smaller dimensions. The RO 4003 material or a material of similar type is preferably used to reduce fabrication problems that may occur with foam materials that can be used to form the insulating substrate 603. A similar application of a thin dielectric layer can be used in any of the antenna configurations illustrated in the other figures herein of the present invention. An RF power source (not shown) is coupled to the antenna through the coaxial line 642 and through the coaxial connector 629 such as an SMA connector (e.g., a SubMiniature version A connector). The location of the feed point 620 for the conductive radiating strip 601 is selected to obtain the required antenna impedance. For the dimensions shown on the figure, the antenna impedance is about 50 ohms. Alternatively, a received signal is produced on the coaxial line 642 by the antenna. The ground plane 602 is formed with a bend 644 proximate an edge, producing a bent portion 641 that lies out of the original plane of the ground plane 602. The conductive radiating strip 601 illustrated on FIG. 6g has an effective electrical length of about a quarter wavelength and has one end open 648 and one end shorted to the ground plane 602 with shorting strip 611. An antenna with a bend in the ground plane constructed in the manner illustrated in FIG. 6g and as described hereinbelow in FIGs. 6h through 6p is not only compact in size, but also exhibits substantial bandwidth. Bandwidths as wide as 6% - 8% or more can be achieved, which is of great benefit to portable communication devices wherein the transmitting or receiving frequency can be readily changed during ordinary use. The gain of this antenna in a preferred direction is about 0 – 2 dBi, i.e., 0 – 2 dB greater than a reference isotropic radiator.

Turning now to FIG. 6h, illustrated is an edge view of a microstrip antenna 600h with a change in separation distance of a conductive radiating strip 601 from a folded ground plane 602. The folded ground plane 602 includes a bend 644 in the folded ground plane 602 proximate an edge, followed by a second bend 664 in the ground plane 602 to form a ground plane segment 663 over a segment of the conductive radiating strip 601, constructed according to principles of the present invention.

Turning now to FIG. 6i, illustrated is an edge view of a microstrip antenna 600i with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, constructed according to principles of the present invention. The microstrip antenna 600i includes a second conductive strip 610 formed as a microstrip line on the back side of the ground plane 602 with its left end 611a shorted to the ground plane 602 and its right end 612 electrically open. The second conductive strip 610 includes two changes in separation distance from the ground plane 602, illustrated as abrupt changes in the figure. The equivalent electrical length of the second conductive strip 610 is preferably configured to be about a quarter of a wavelength for the signal to be transmitted or received, but odd multiples of about a quarter wavelength can also be used. The second conductive strip is operative as a quarter wavelength transformer, providing a very large impedance at the open end. Thus, when a finite voltage is applied at the open end, the current that flows into the open end is very small. Currents ordinarily conducted around the right upper edge 623 encounter an open circuit at the frequency of the signal to be transmitted, and are reflected back onto the top side 622 of the ground plane 602 as described hereinabove.

Elements in FIG. 6h or in FIGs. 6i through 6p below that are similar to elements illustrated in FIG. 6g will not be re-described in the interest of brevity.

Turning now to FIG. 6j, illustrated is an edge view of a microstrip antenna 600j with one change in separation distance of a conductive radiating strip 601 from a ground plane 602, and a second conductive strip 610 with an equivalent electrical length of a quarter-wavelength on the back side of the ground plane 602 also with one change in separation distance from the ground plane 602, constructed according to principles of the present invention. The second conductive strip 610 formed as a microstrip line on the back side of the ground plane 602 has its left end 611a shorted to the ground plane 602 and its right end 612 electrically open. The second conductive strip 610 is operative to reflect currents back onto the topside of the ground plane 602 as described hereinabove.

Turning now to FIG. 6k, illustrated is an edge view of a microstrip antenna 600k with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, constructed according to principles of the present invention. A microstrip antenna with multiple changes in separation distance of a conductive radiating strip 601 from a ground plane 602 is in accordance with further aspects of the present invention. The ground plane 602 is formed with a bend 644 proximate an edge, producing a bent portion 641 that lies out of the original plane of the ground plane 602. The bend 644 illustrated in FIG. 6k exceeds a right-angle bend that can be effective for producing an efficient, wide bandwidth antenna. Alternatively, the bend 644 can be formed at an angle that is less than a right angle.

Turning now to FIG. 6ℓ, illustrated is an edge view of a microstrip antenna 600ℓ with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, and including a second conductive strip 610 with an equivalent electrical length of a quarter-wavelength on the backside of the ground plane 602, constructed according to principles of the present invention. The second conductive strip 610 is formed with a bend 649 proximate an edge, producing a bent portion 647 that lies out of the original plane of the second conductive strip 610. The bend 649 illustrated in FIG. 6ℓ exceeds a right-angle bend, and, in conjunction with the bend 644 in the ground plane 602, can be effective for producing an efficient, wide bandwidth antenna. Alternatively, the bend 649 can be formed at an angle that is less than a right angle.

Turning now to FIG. 6m, illustrated is an edge view of a microstrip antenna 600m with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, and a second conductive strip 610 with an equivalent electrical length of a quarter-wavelength on the back side of the ground plane 602, with only one change in separation distance from the ground plane 602, constructed according to principles of the present invention. Both the ground plane 602 and the second conductive strip 610 are illustrated with bends 644 and 649 exceeding a right angle. Alternatively, the bend 649 can be formed at an angle that is less than a right angle. The bends illustrated in FIG. 6m can be effective for producing an efficient, wide bandwidth antenna.

Turning now to FIG. 6n, illustrated is an edge view of a microstrip antenna 600n with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, and including a tapered portion 645 of the conductive radiating strip 601, constructed according to principles of the present invention. The interior portion 643 of the tapered conductive radiating strip may be hollow or filled. The fill material may be conductive or nonconductive. A gap that may be about 0.080 inch is formed between the right edge 646 of the tapered conductive radiating strip and the bend 644 in the ground plane 602 to facilitate producing a radiating field above the tapered conductive radiating strip. The ground plane 602 is formed with a bend 644 proximate an edge, producing a bent portion 641 that lies out of the original plane of the ground plane 602. The bend illustrated in FIG. 6n is a right-angle bend that can be effective for producing an efficient, wide bandwidth antenna.

Turning now to FIG. 6o, illustrated is an edge view of a microstrip antenna 600o with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, including a tapered portion 645 of the conductive radiating strip 601 as described in conjunction with FIG. 6n above, and further including a second conductive strip 610 with an equivalent electrical length of a quarter-wavelength on the back side of the ground plane 602, including a change in its separation distance from the ground plane 602, constructed according to principles of the present invention. The second conductive strip 610 is formed with a bend 649 proximate an edge, producing a bent portion 647 that lies out of the original plane of the second conductive strip 610. The bend 649 illustrated in FIG. 6ℓ is substantially or exceeds a right-angle bend, and, in conjunction with the bend 644 in the ground plane 602, can be effective for producing an efficient, wide bandwidth antenna.

Turning now to FIG. 6p, illustrated is an edge view of a microstrip antenna 600p with a change in separation distance of a conductive radiating strip 601 from a ground plane 602, including a tapered portion 645 of the conductive radiating strip 601 as described in conjunction with FIG. 6n above, and further including a second conductive strip 610 with an equivalent electrical length of a quarter-wavelength on the back side of the ground plane 602, but including a single change in its separation distance from the ground plane 602, constructed according to principles of the present invention. The ground plane 602 and the second conductive strip 610 may be formed with bends proximate an edge that are substantially at right angles as shown in FIG. 6p, producing bent portions 641 and 647 that lie out of their original planes. Alternatively, the bends may be formed at angles that are greater than or less than right angles. The bends illustrated in FIG. 6k can be effective for producing an efficient, wide bandwidth antenna. The bending is done such that the impedance of the radiating edge is transformed to the free-space impedance at the end of the transition.

The antenna of various embodiments can be used in a large number of applications. One example is an RF tag, such as those used for toll collections, inventory tracking, and the like. Another example is a cellular telephone, which can especially take advantage of the reduced SAR of various ones of the embodiments. An example of a cellular telephone is shown in FIGs. 7 and 8 as described below.

Turning now to FIG. 7, illustrated is a representative block diagram of a cellular telephone set 700 constructed according to principles of the present invention. A cellular telephone set 700 is a device configured to transmit and receive the complex signals necessary to accommodate reliable one-on-one duplex communication in a multi-party, multi-frequency, multi-base station, mobile environment. The blocks shown on FIG. 7 are not arranged in a unique manner, but are representative of essential functions that must be performed.

The antenna 701, however, is a basic function in the design of a cellular telephone set 700, not only in its being in-line in both the transmitting and receiving paths, but its ability to be implemented in a small size with low SAR is essential to long term and continued widespread use of cellular telephony without concern about possibly subtle or adverse effects on human health. Thus, the miniaturization of cellular telephones and the reduction of the near-field radiation pattern on the backside of a ground plane make it an inseparable part of a design.

The remaining parts shown on FIG. 7 are the transmit/receive switch 781 that selectively couples the antenna 701 to the transmitting or receiving path depending on the state of the set 700. The receiving path includes a receiver block 782 and a demodulator block 783 that include amplification, filtering, frequency shifting, and detection functions necessary to extract audio and other information from an incoming signal. Further signal processing may be performed as necessary by a signal processing block 784 before the signal is coupled to a loudspeaker 785a.

The transmitting path includes a modulator 788, oscillator 789b, and a transmitter power amplifier 789a. An audio signal is shown generated by a microphone 785b coupled to the signal processing block 784. Both the transmitting and receiving paths are controlled by the signal processing block, such as represented by block 784, to provide automatic duplex operation.

Power for operation of all functions is provided by a battery 787a coupled to a power converter 787b that generally supplies multiple output voltages such as V_1 and V_2 to the various functional portions of the circuit.

It is recognized that a practical implementation of a cellular telephone requires substantial circuit integration such as in silicon, which provides numerous opportunities for complex processing and interconnection among circuit functions. The arrangement on FIG. 7 is intended only to illustrate a general signal flow, and may not represent the design of a specific product.

Turning now to FIG. 8, illustrated is a sketch of a cellular telephone set 800 constructed according to principles of the present invention. The cellular telephone set 800 includes a loudspeaker 891, a microphone 894, a keypad 893, a display 892 and a battery 887a. Controls and other elements, such as power and function buttons are omitted from the sketch for simplicity.

The cellular telephone set 800 includes a microstrip antenna 800a on the back side of the set 800, with a conductive strip 810 above a back side of an antenna ground plane (not shown) constructed according to principles of the present invention. The microstrip antenna 800a is shown enlarged as 800b. A conductive strip 810 is circularly configured as shown on the figure with an outer end that is intended to be proximate an outer edge of the antenna ground plane. The conductive strip 810 can be configured to be operative to obstruct RF current flow on the side of the antenna ground plane facing a person's head, thereby reducing SAR. Thus, an integrated design of a cellular telephone set can be accommodated that is compact, efficient, and operable over extended periods of time without concern about absorbed radiation and the possible consequences for a person's health.

Although the present invention has been described in detail and with reference to particular embodiments, those skilled in the art should understand that various changes, substitutions and alterations can be made as well as alterative embodiments of the invention without departing from the spirit and scope of the invention in its broadest form.

WHAT IS CLAIMED IS:

1. An antenna comprising:

an insulating substrate;

a conductive strip with two ends disposed on a first surface of the substrate, the conductive strip having a characteristic impedance that may vary along its length wherein the conductive strip is separated from the ground plane by a separation distance, the separation distance being changed at at least one location along the conductive strip; and

a ground plane disposed on a second surface of the substrate, the second surface being opposed to the first surface, wherein the ground plane is formed with a bend proximate an edge.

2. The antenna of claim 1, wherein the conductive strip is insulated from the ground plane except at a point.

3. The antenna of claim 1, wherein the bend in the ground plane is an angular bend.

4. The antenna of claim 1, wherein the bend in the ground plane is substantially a right angle.

5. The antenna of claim 1, wherein a second bend is formed in the ground plane to form a segment of the ground plane lying over the conductive strip.

6. The antenna of claim 1, wherein the conductive strip is formed with a tapered section proximate an end.

7. The antenna of claim 6, wherein the tapered section is hollow.

8. The antenna of claim 1, wherein said separation distance of the conductive elements is changed abruptly along the length of the conductive patch.

9. The antenna of claim 1 and further comprising a feed point proximate the shorted end of said microstrip line.

10. The antenna of claim 1 and further comprising a lossy magnetic material disposed over at least a portion of said ground plane.

11. The antenna of claim 1 and further comprising another conductive element disposed over a side of said ground plane opposing the conductive strip and insulated from said ground plane except at a point.

12. The antenna of claim 11, wherein the another conductive element has an end that is proximate an edge of said ground plane and wherein a bend is formed in said another conductive element proximate said edge.

13. The antenna of claim 11, wherein the bend formed in said another conductive element is an angular bend.

14. The antenna of claim 11, and further comprising an insulating material having a varied thickness disposed between the another conductive element and said ground plane.

15. The antenna of claim 11, wherein the thickness of the insulating material disposed between the another conductive element and said ground plane varies abruptly at at least one location.

16. The antenna of claim 1, wherein the substrate is formed from a material with a relative dielectric constant substantially equal to 1.

17. A method of producing an antenna, the method comprising:

forming an insulating substrate;

configuring a conductive strip on a first surface of the substrate, the conductive strip having a characteristic impedance that may vary along its length, wherein the conductive strip is separated from the ground plane by a separation distance, the separation distance being changed at at least one location along the conductive strip; and

configuring a ground plane on a second surface of the substrate, the second surface being opposed to the first surface, wherein a bend is formed in the ground plane proximate an edge.

18. The method of claim 17, wherein the bend is an angular bend.

19. The method of claim 17, wherein said separation distance of the conductive elements is changed abruptly along the length of the conductive strip.

20. The method of claim 17, wherein another conductive element is disposed over a side of the ground plane opposing the conductive strip and insulated from the ground plane except at a point.

21. The method of claim 17, wherein the another conductive element has an end that is proximate an edge of said ground plane.

22. The method of claim 17, wherein the bend in the ground plane is substantially a right angle.

23. The method of claim 17 including forming a second bend in the ground plane to form a segment of the ground plane lying over the conductive strip.

24. The method of claim 17, wherein the conductive strip is formed with a tapered section proximate an end.

25. An RF communication device comprising:

a transmitter;

a receiver; and

an antenna coupled to the transmitter and receiver, the antenna having an insulating substrate, a conductive strip disposed on a first surface of the substrate, and a ground plane disposed on a second surface of the substrate, the second surface being opposed to the first surface, wherein the conductive strip is separated from the ground plane by a separation distance, the separation distance being changed at at least one location along the conductive strip, and wherein the ground plane is formed with a bend proximate an edge.

26. The device of claim 25, wherein said separation distance of the conductive elements is changed abruptly along the length of the conductive patch.

27. The device of claim 25 and further comprising another conductive element disposed over a side of the ground plane

28. The device of claim 25, wherein the another conductive element has an end that is proximate an edge of said ground plane.

29. The device of claim 25, wherein the RF communication device comprises a cellular telephone.

30. The device of claim 25, wherein the RF communication device comprises an RF identification tag.

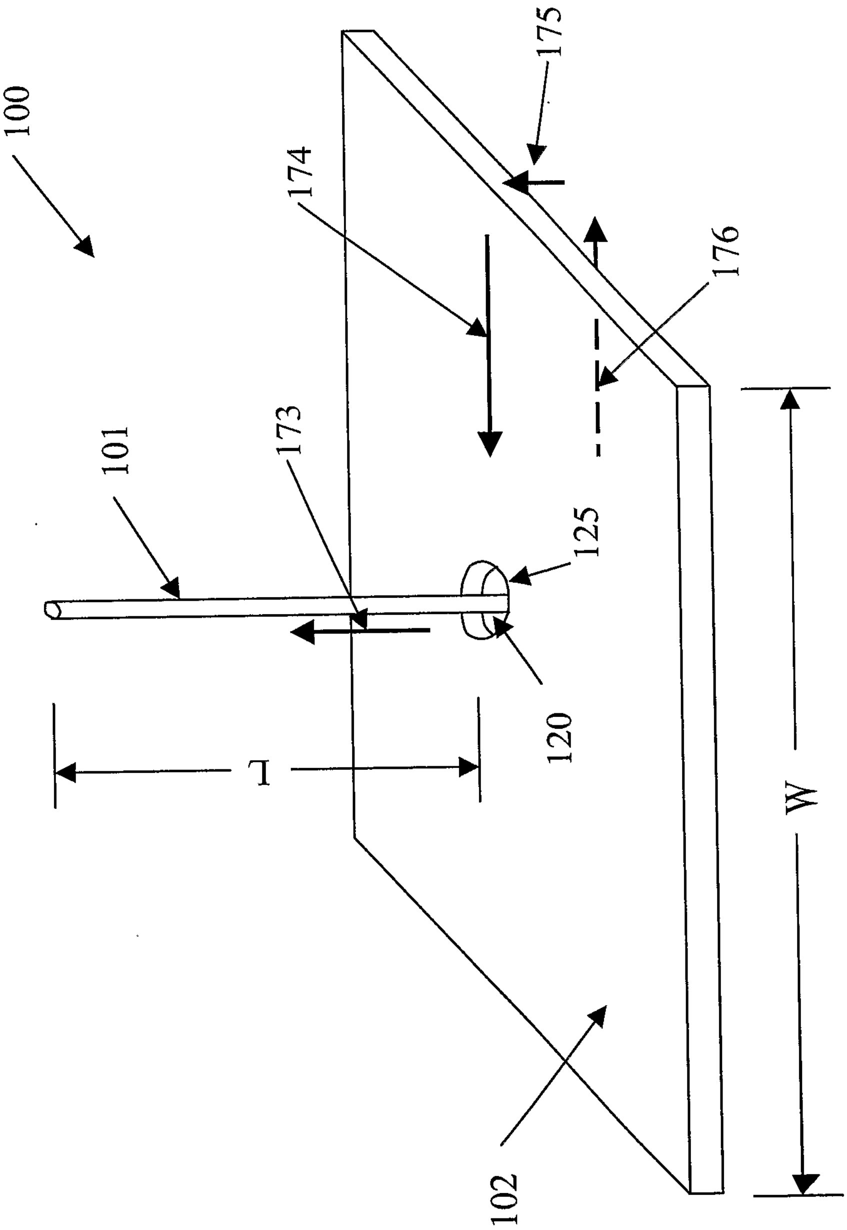


FIGURE 1 PRIOR ART

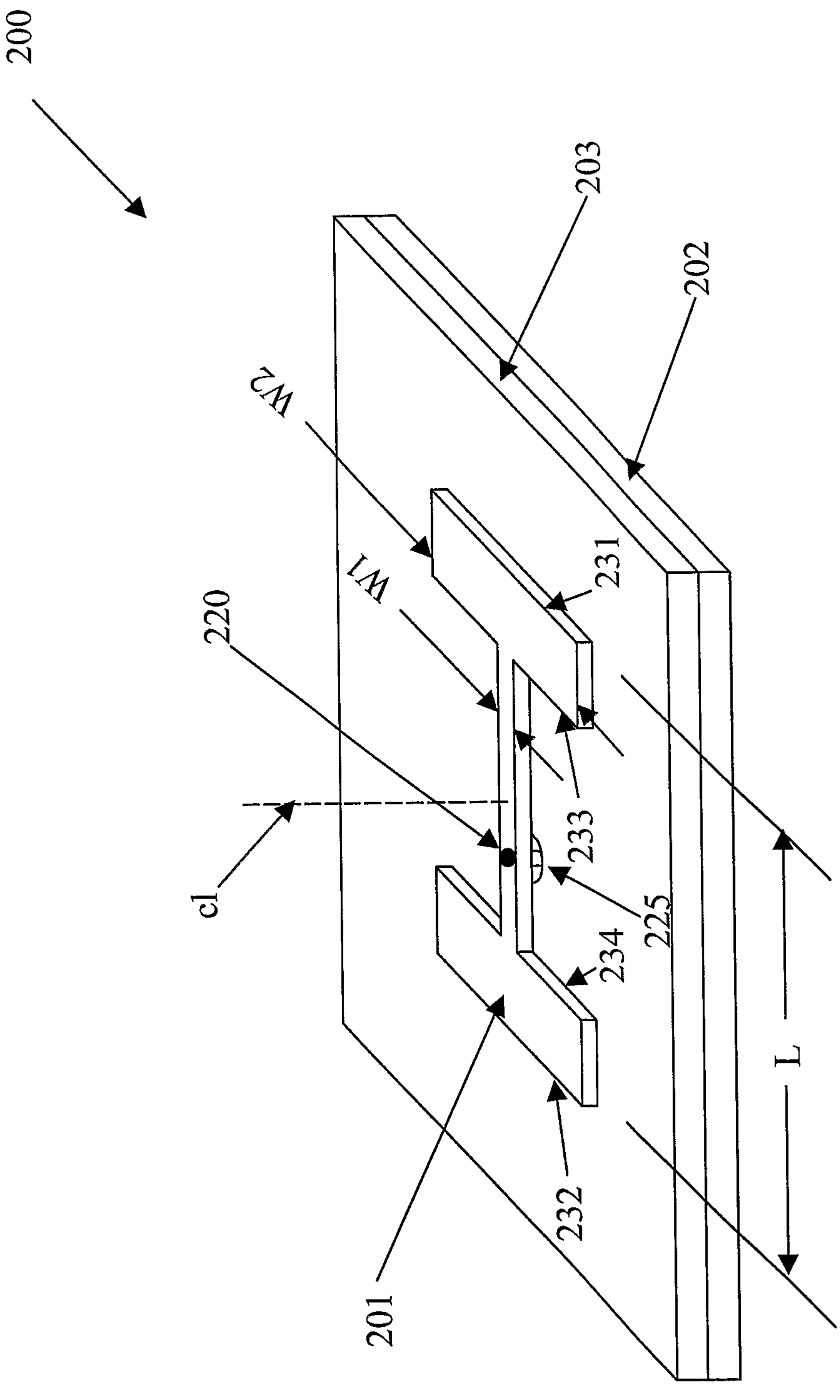


FIGURE 2

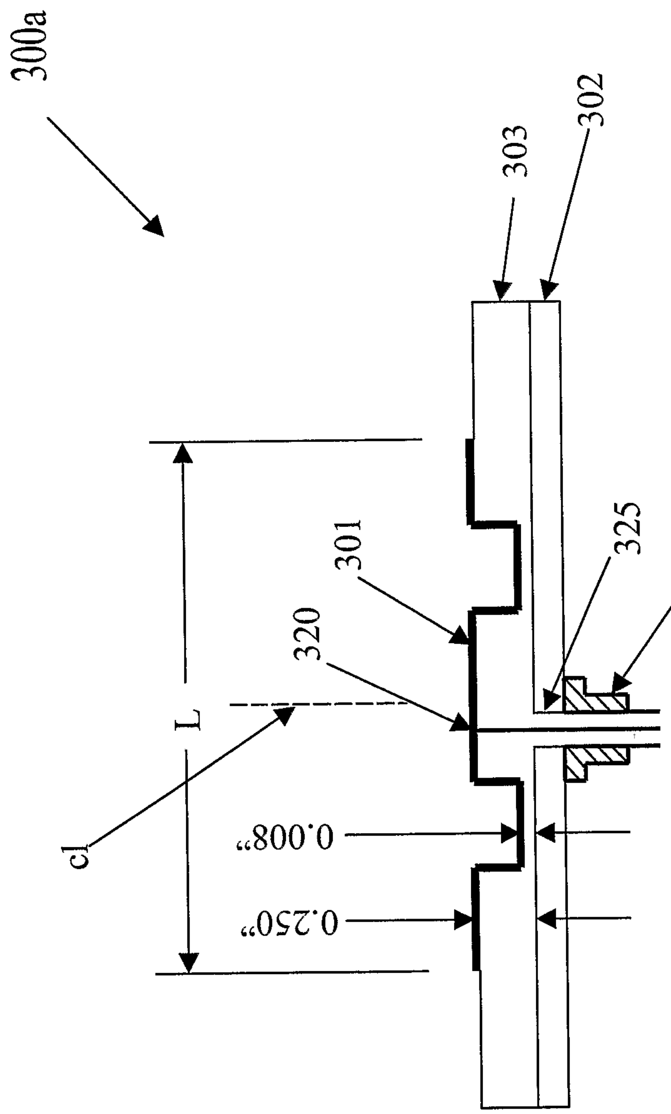


FIGURE 3a

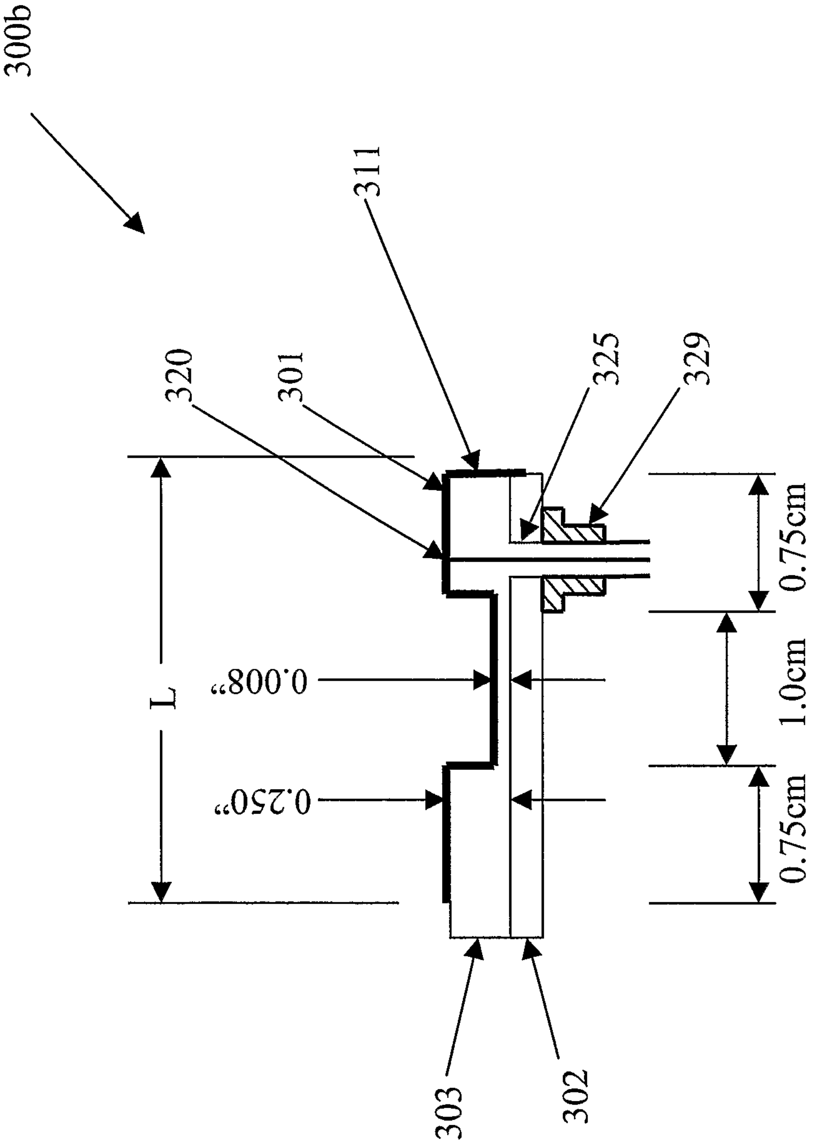


FIGURE 3b

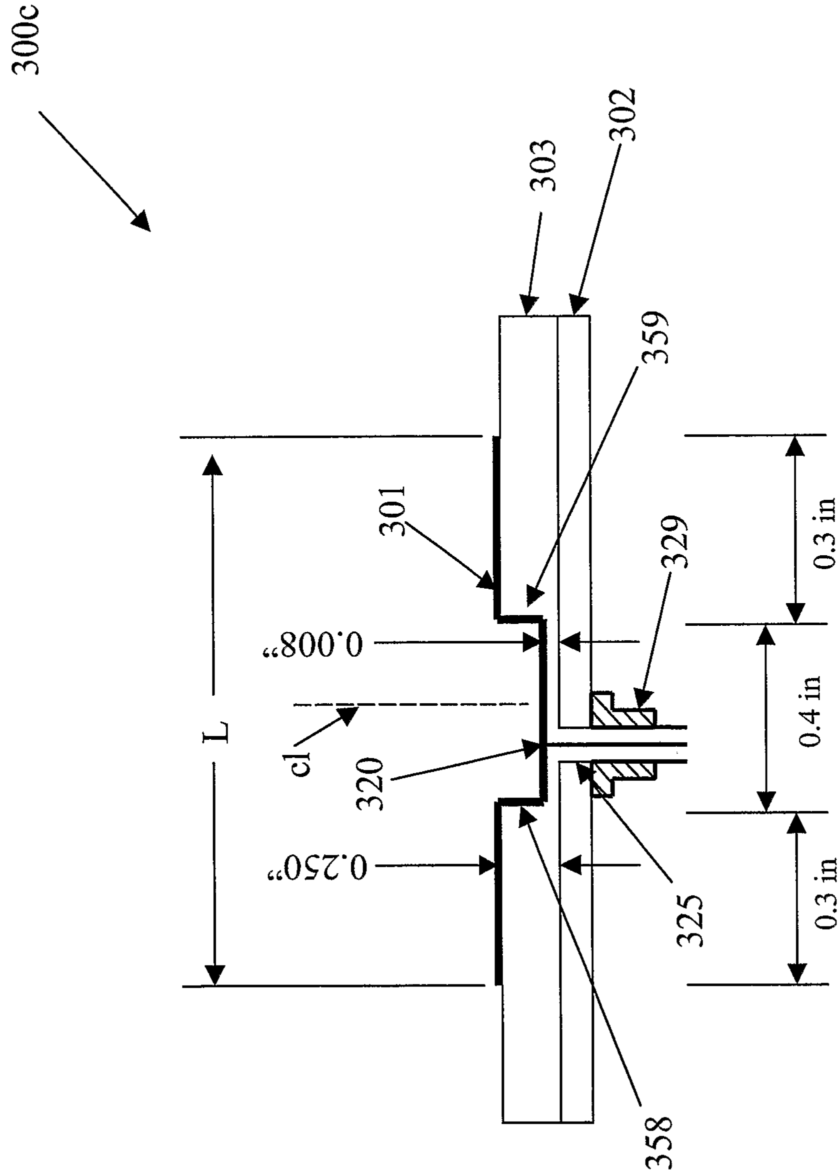

300c
303
302
359
301
329
0.3 in
0.008"
L
cl
320
0.4 in
0.250"
325
0.3 in
358

FIGURE 3c

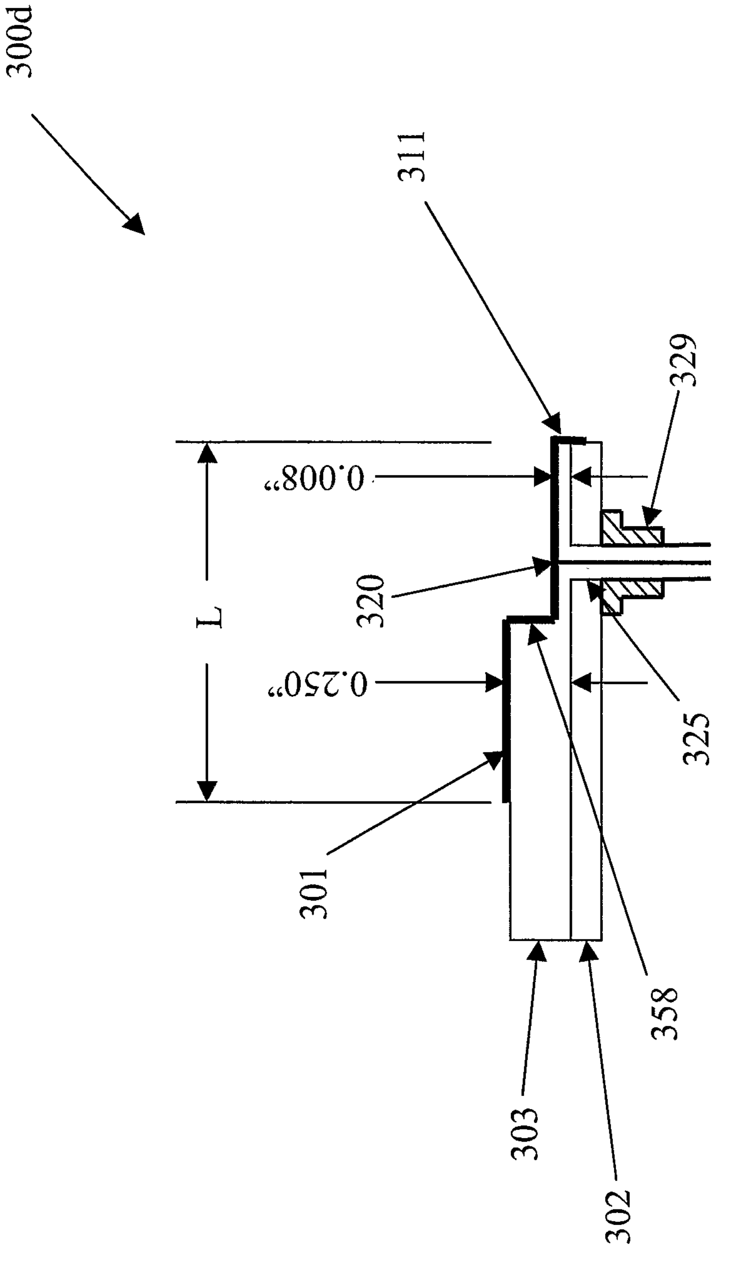


FIGURE 3d

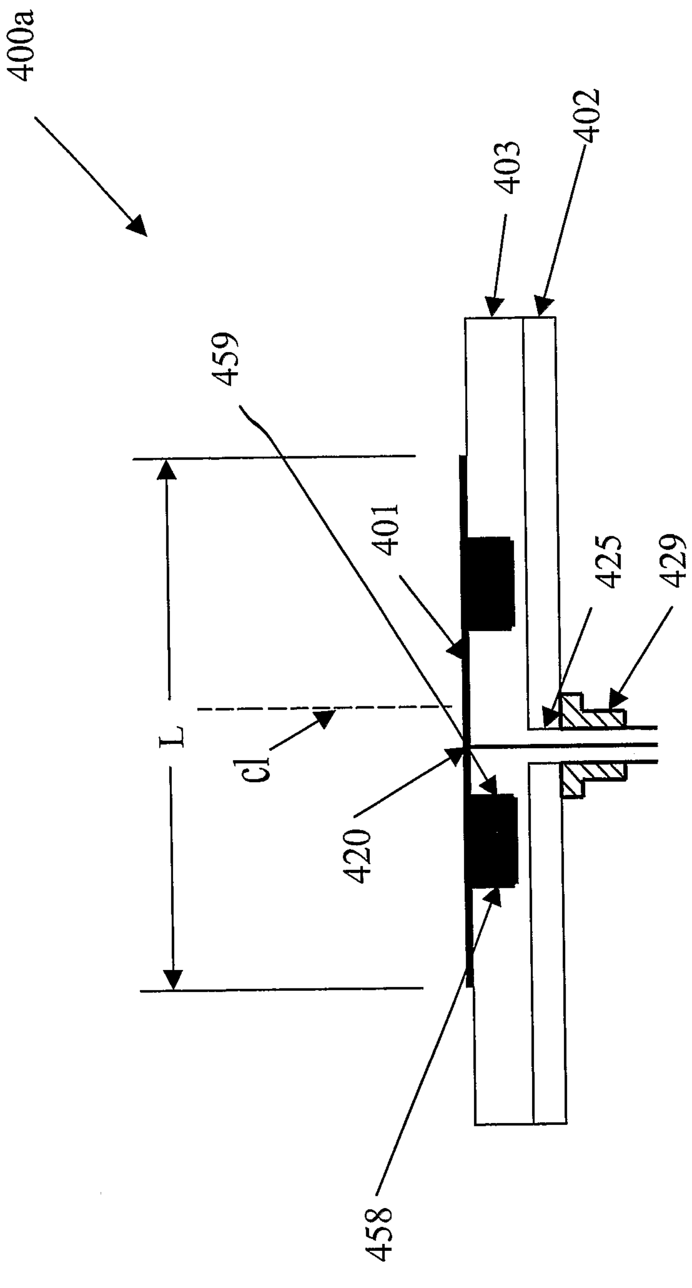


FIGURE 4a

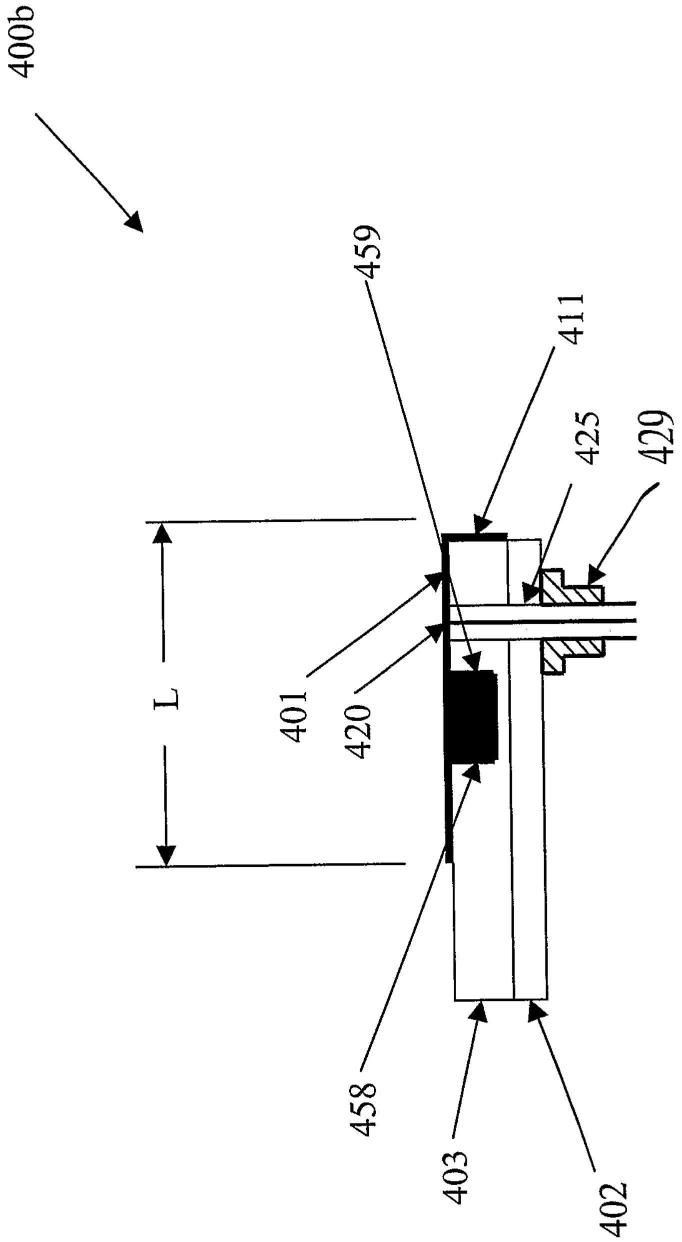


FIGURE 4b

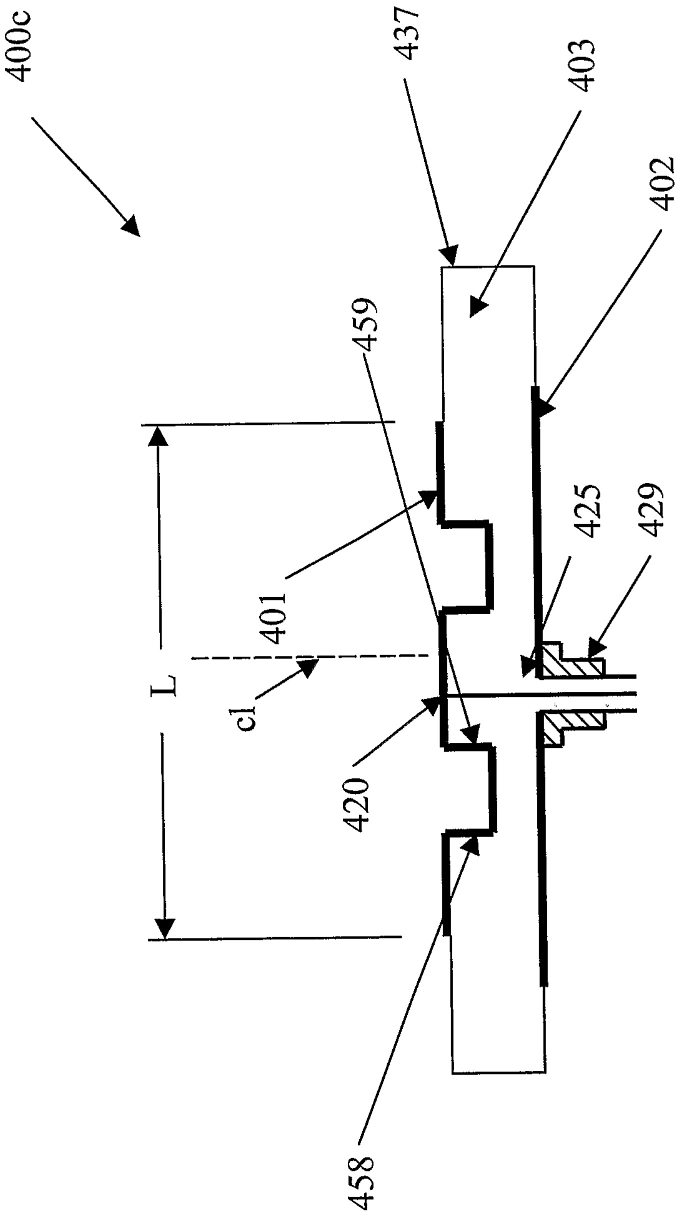


FIGURE 4c

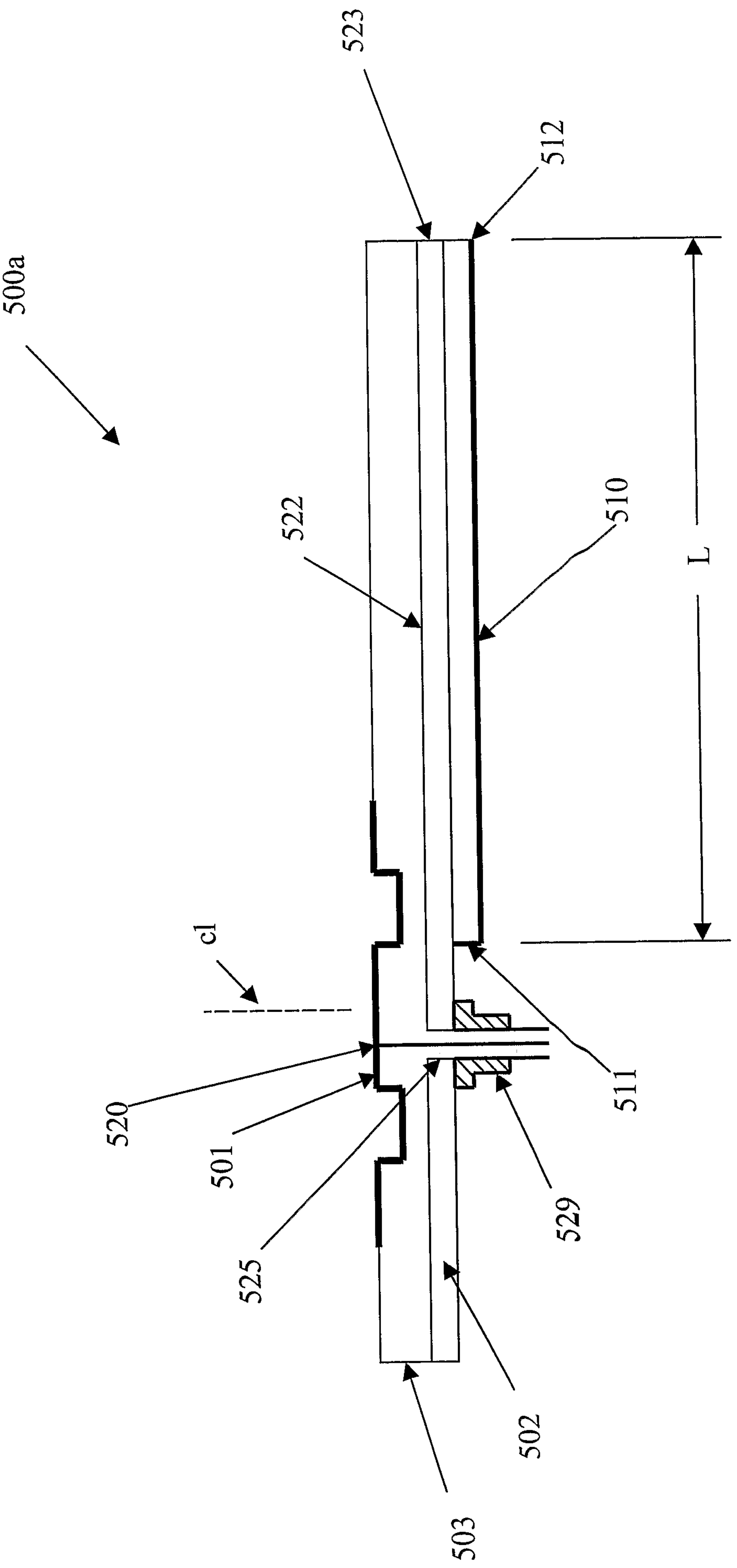


FIGURE 5a

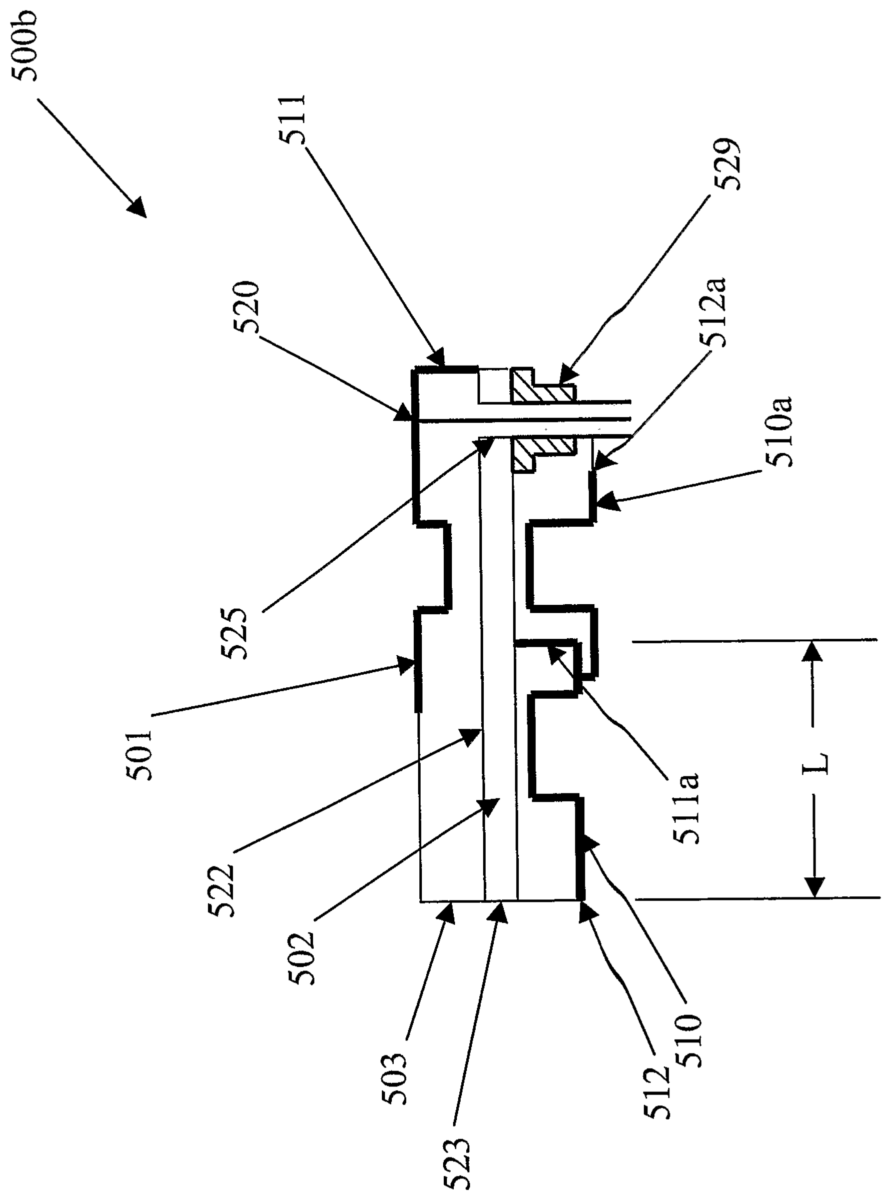

500b
511
529
520
512a
510a
525
501
511a
L
522
502
503
523
512
510

FIGURE 5b

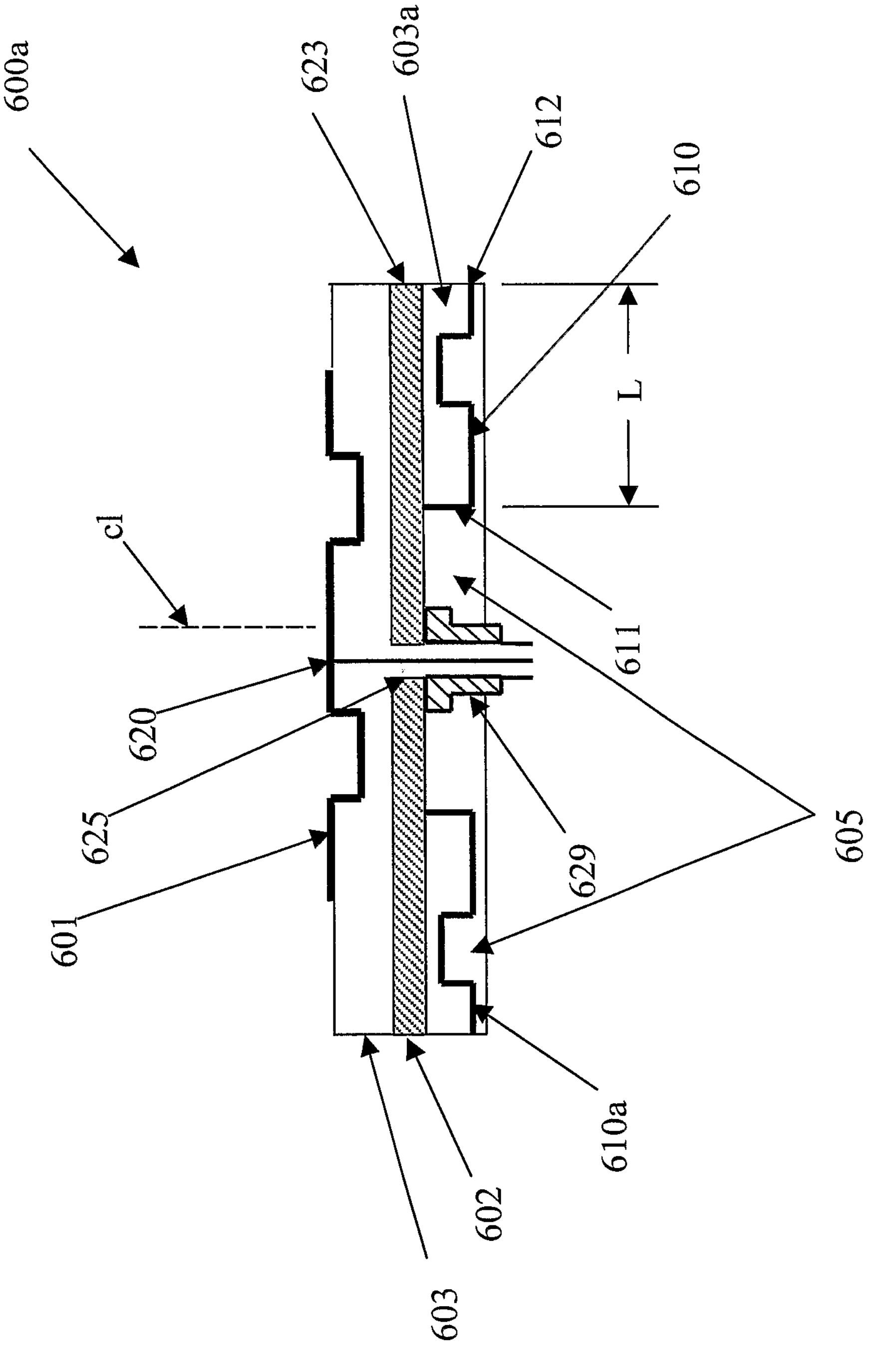


FIGURE 6a

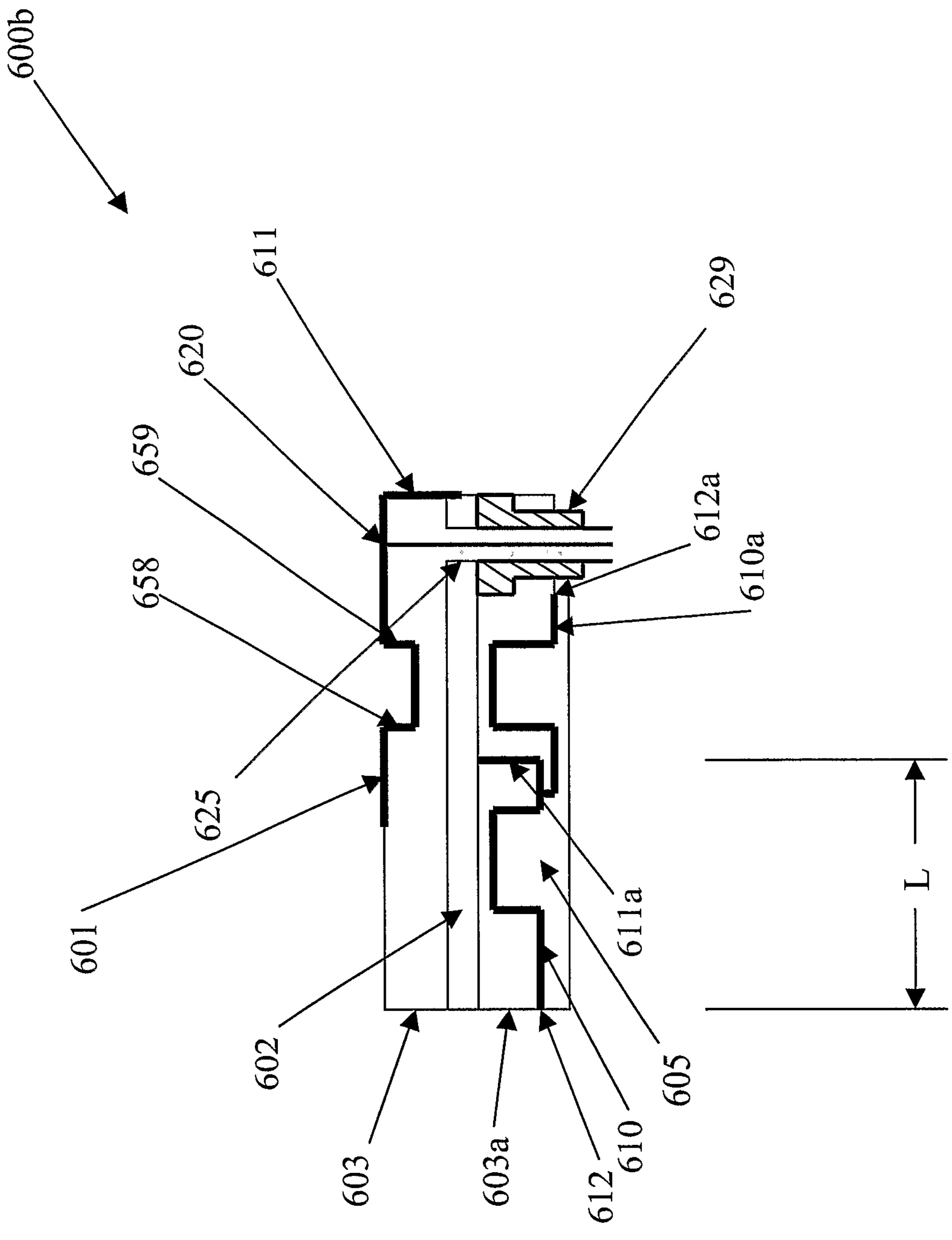

600b
611
620
659
658
625
601
629
612a
610a
611a
L
602
605
610
612
603a
603

FIGURE 6b

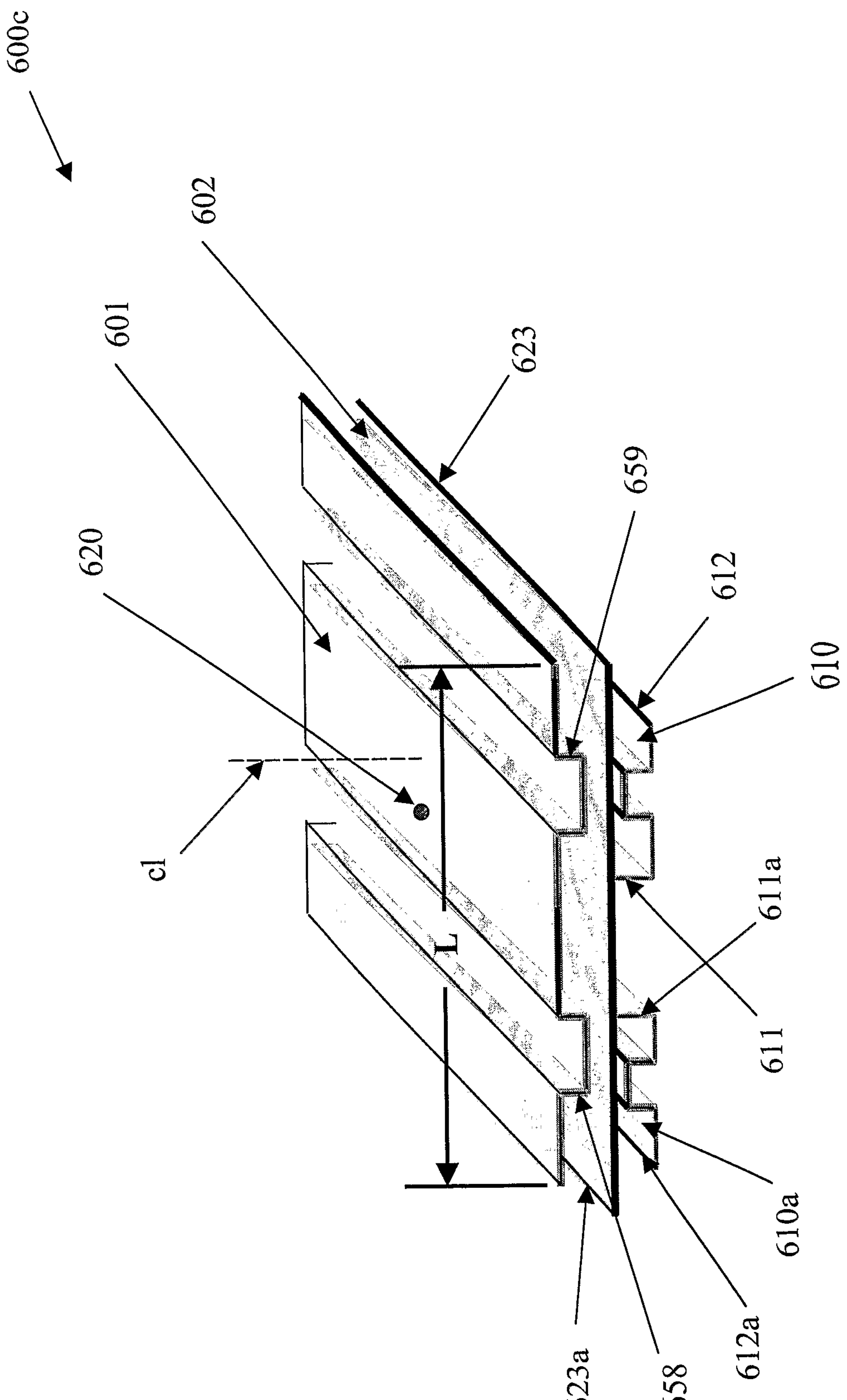

600c
602
601
623
620
659
612
610
cl
L
611a
611
610a
612a
658
623a

FIGURE 6c

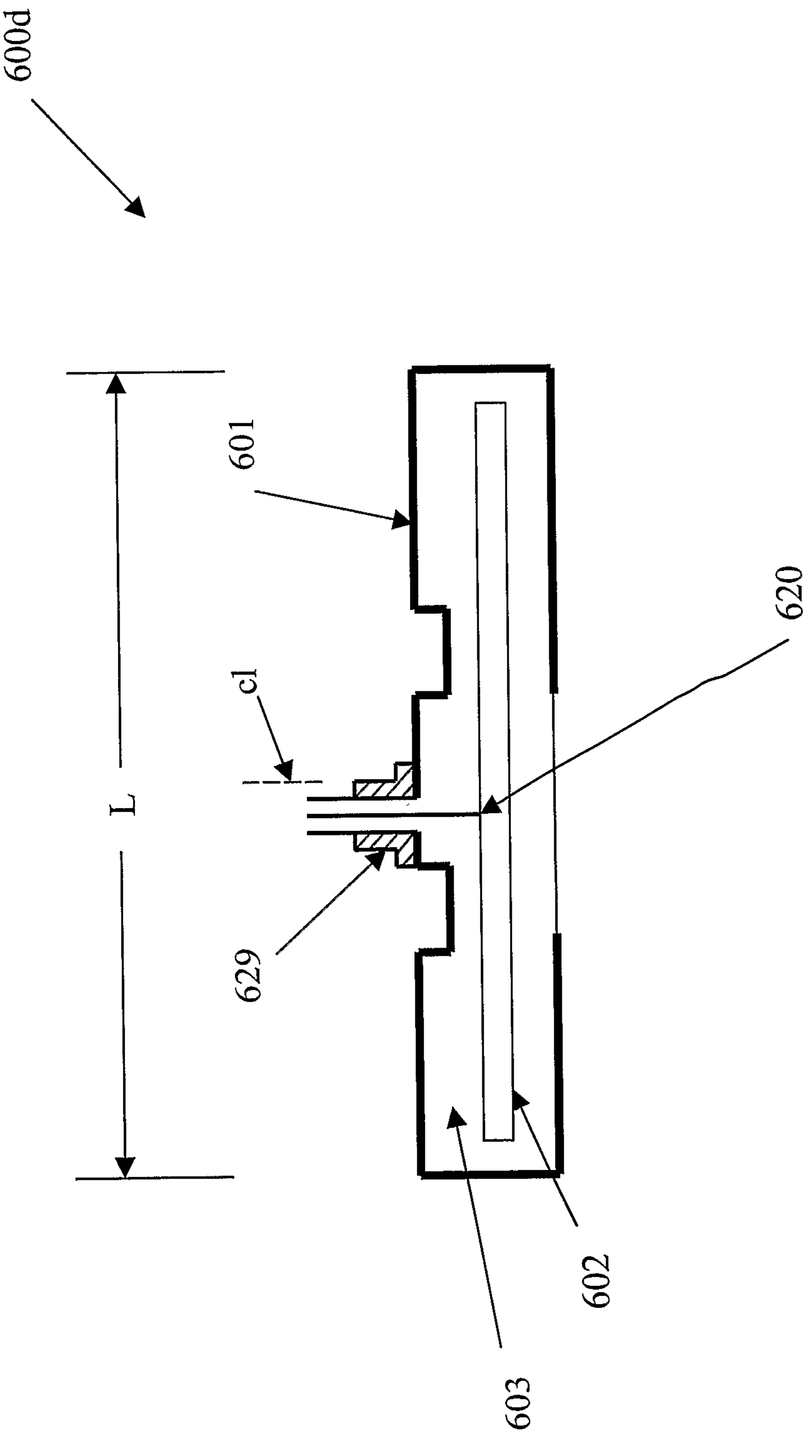


FIGURE 6d

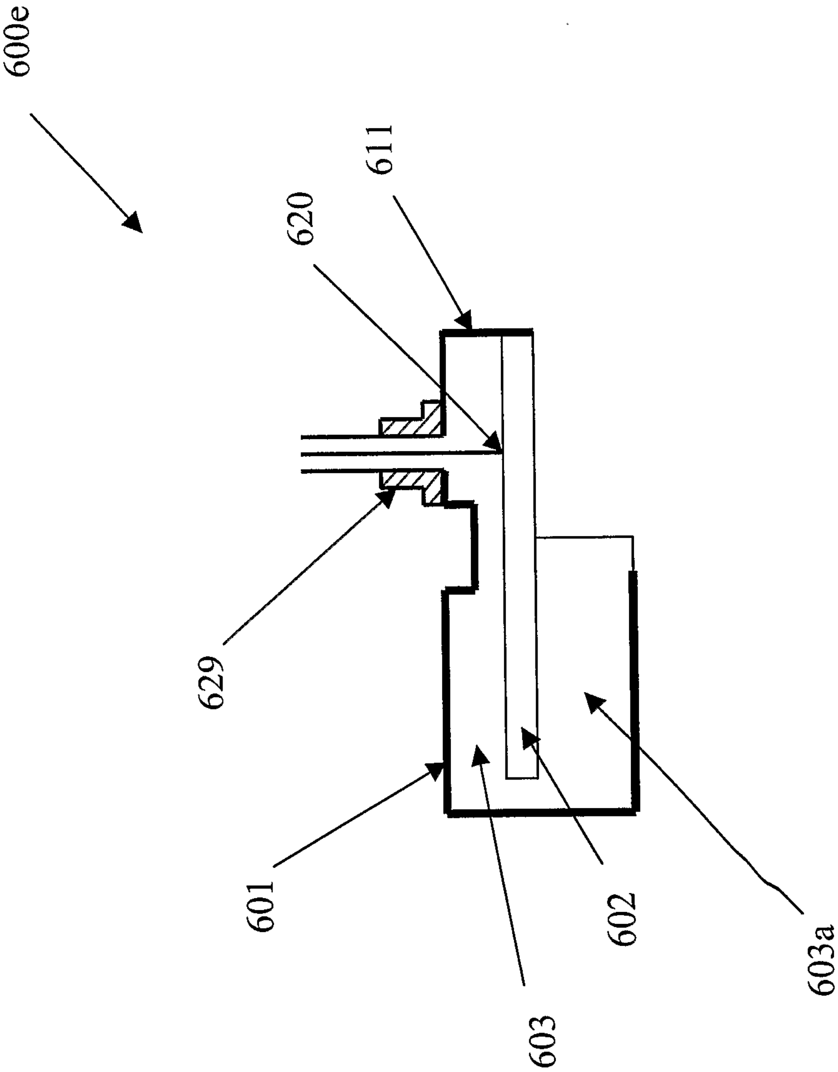


FIGURE 6e

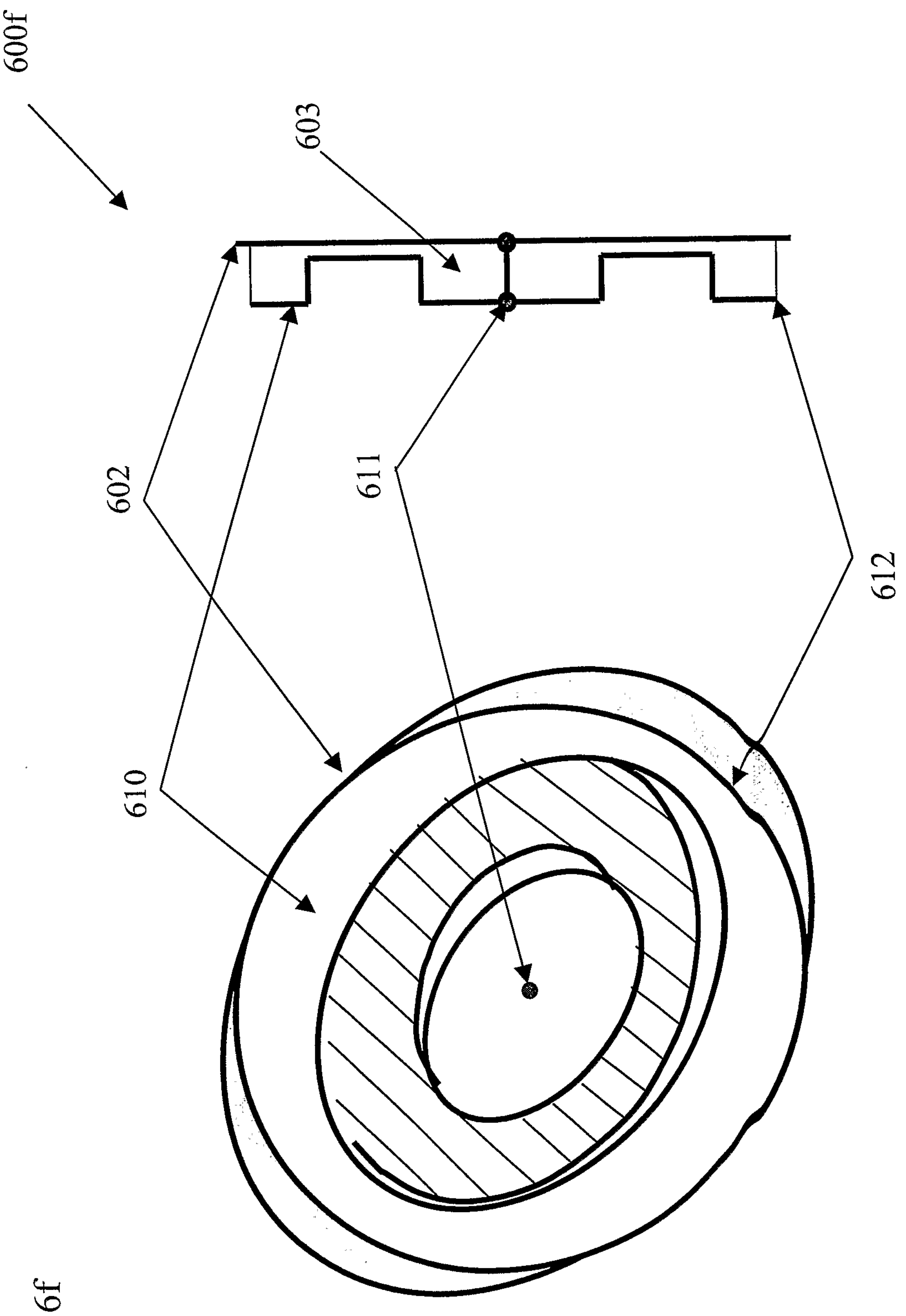


FIGURE 6f

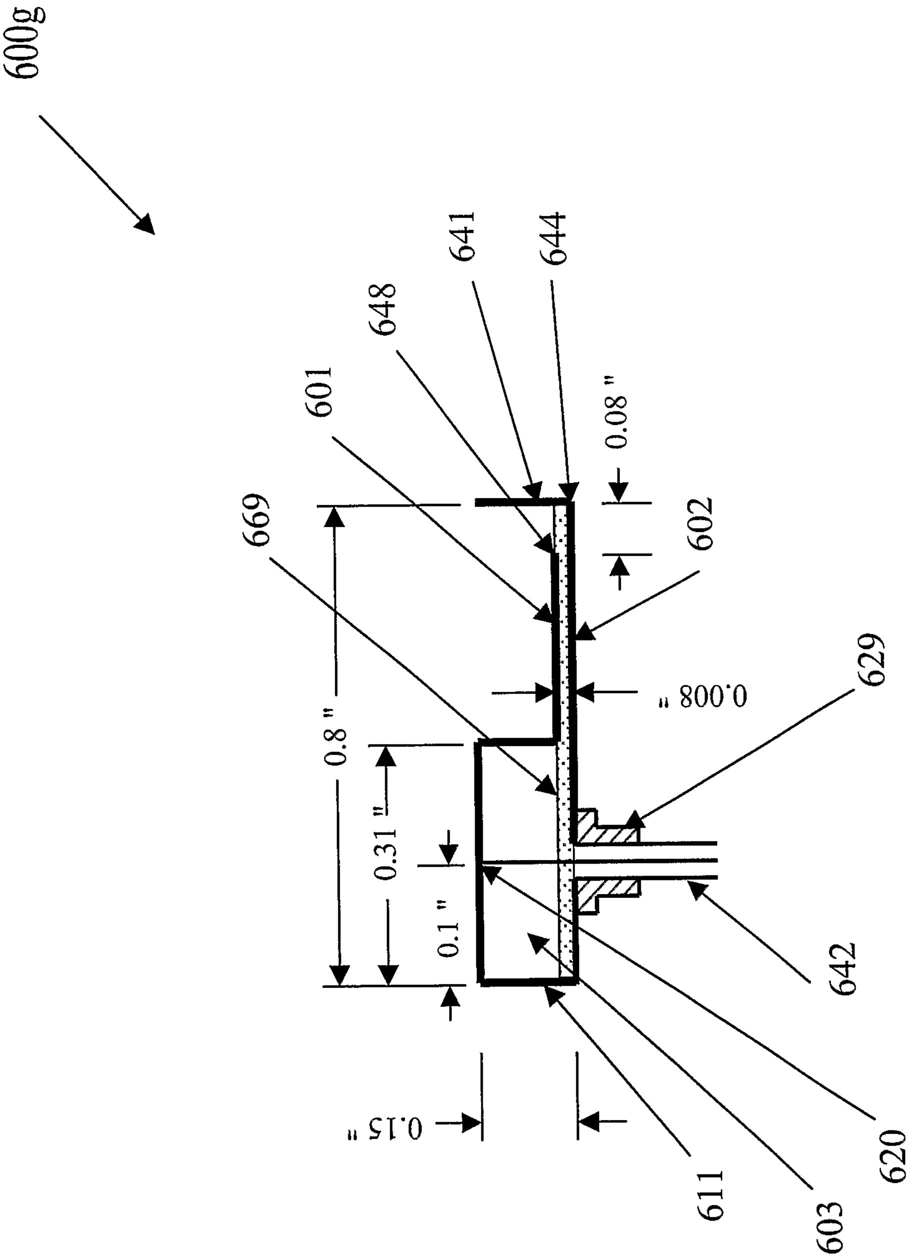

600g
669
601
648
641
644
0.08 "
602
0.008 "
629
0.8 "
0.31 "
0.1 "
642
0.15 "
611
603
620

FIGURE 6g

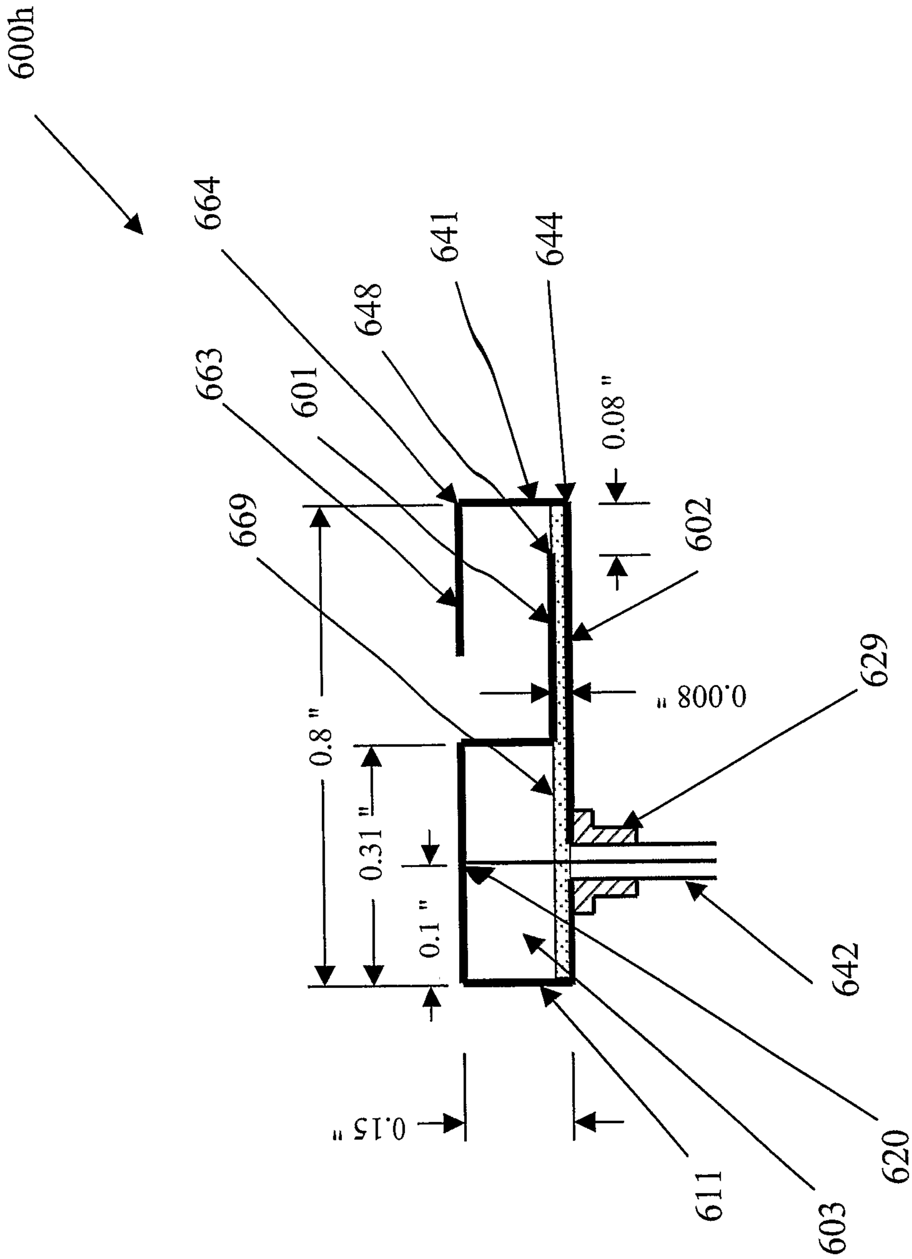

600h
664
641
644
648
663
601
0.08 "
669
602
0.008 "
629
0.8 "
0.31 "
0.1 "
642
0.15 "
611
603
620

FIGURE 6h

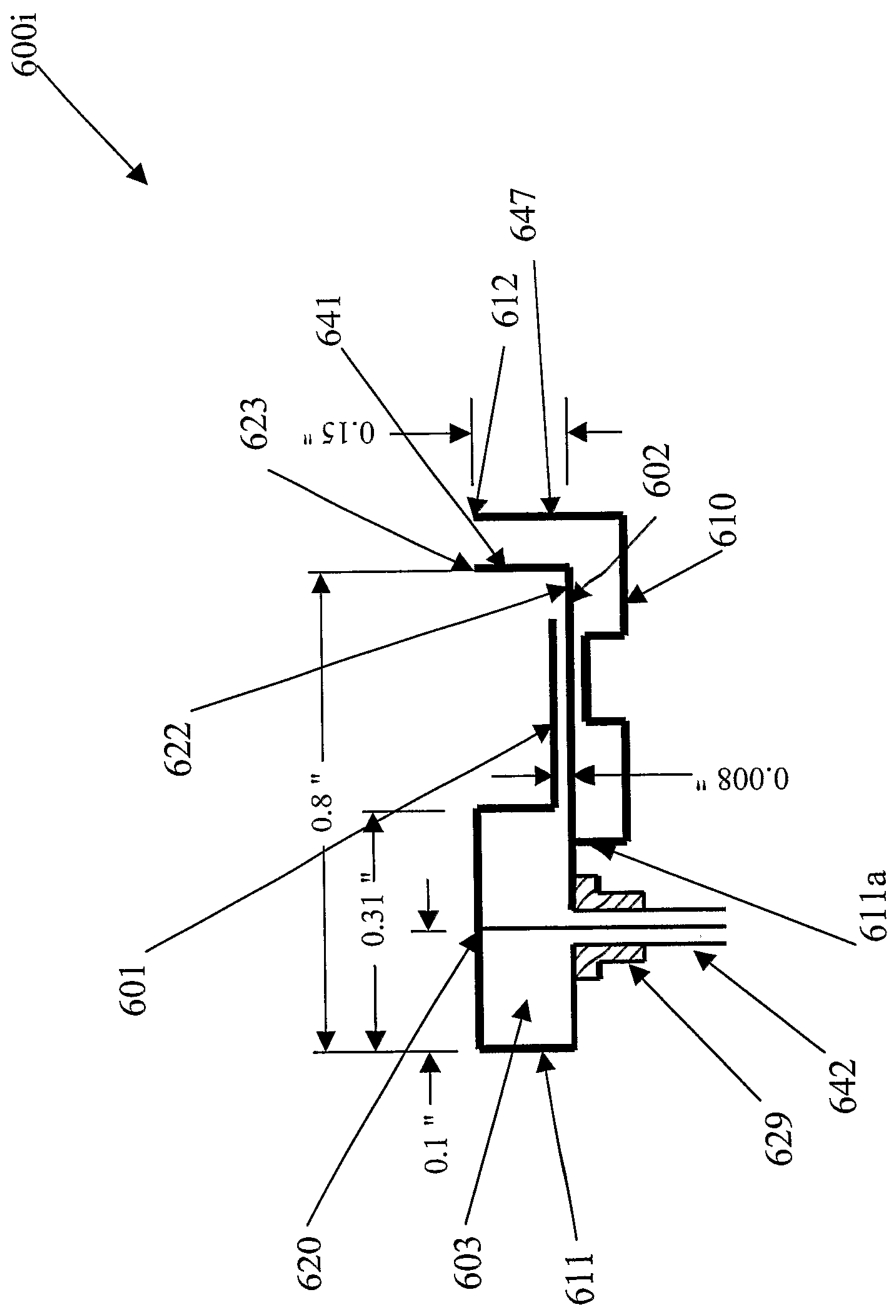

600i
647
612
641
623
0.15 "
602
610
622
0.008 "
0.8 "
0.31 "
601
611a
642
629
0.1 "
620
603
611

FIGURE 6i

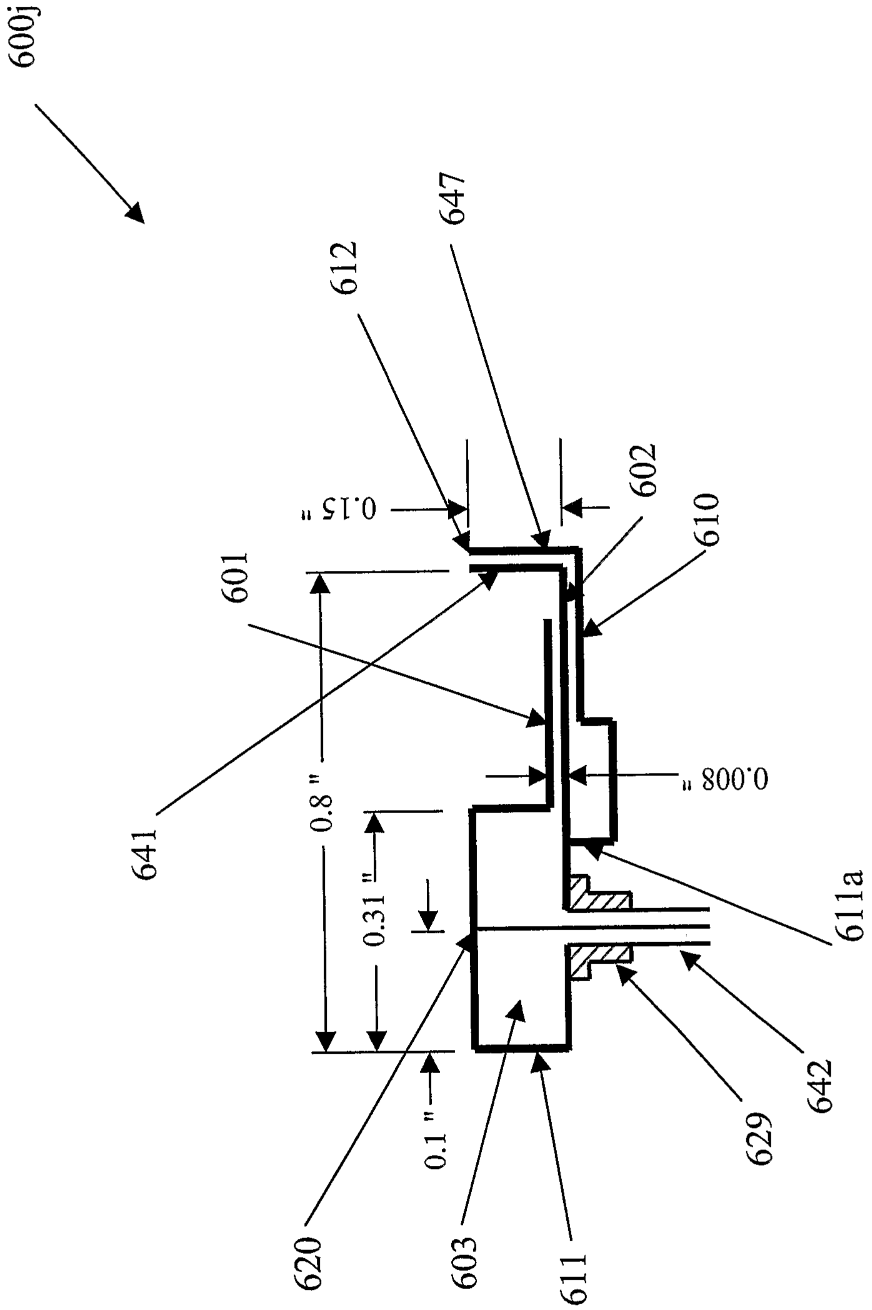

600j
647
612
0.15 "
602
610
601
641
0.008 "
0.8 "
0.31 "
611a
642
629
0.1 "
620
603
611

FIGURE 6j

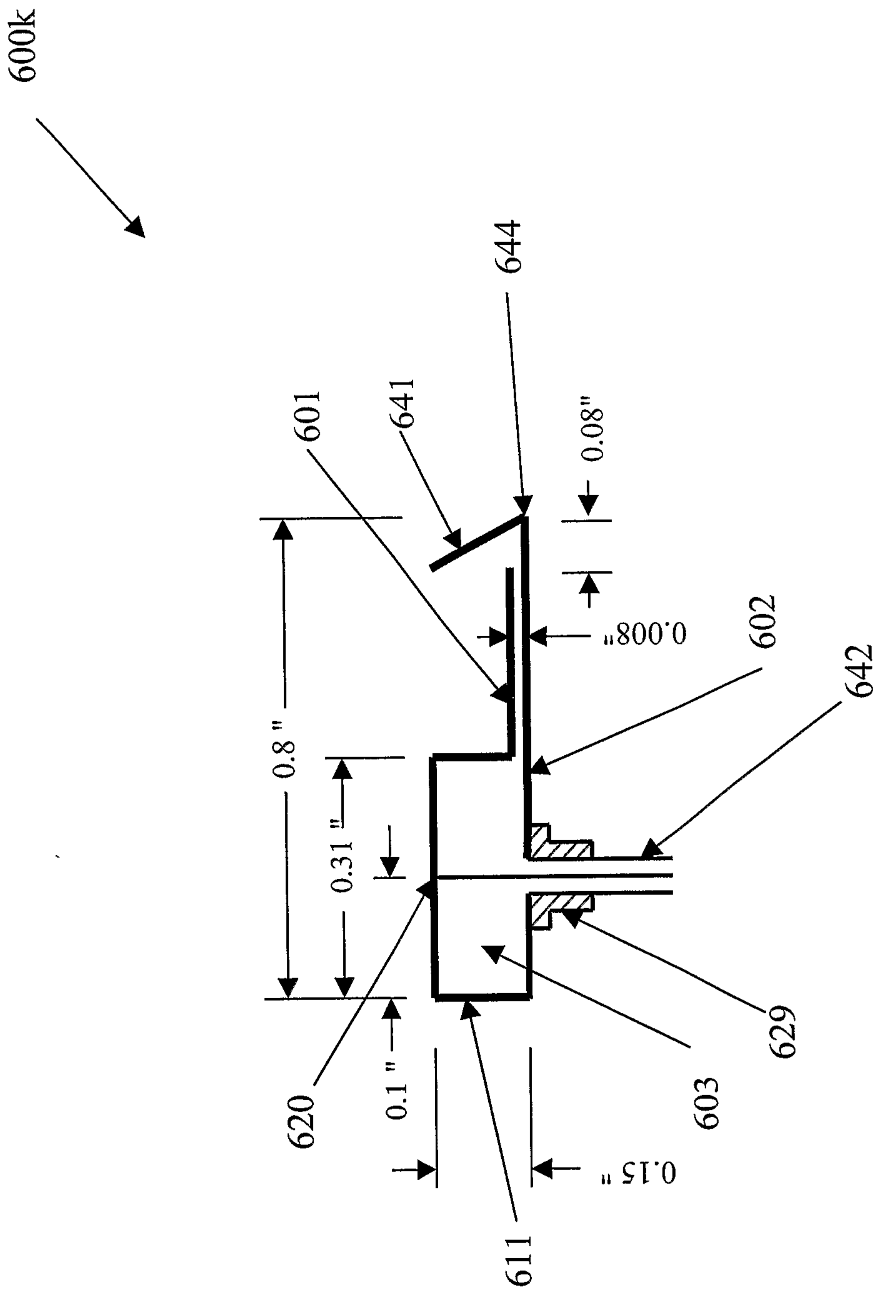


FIGURE 6k

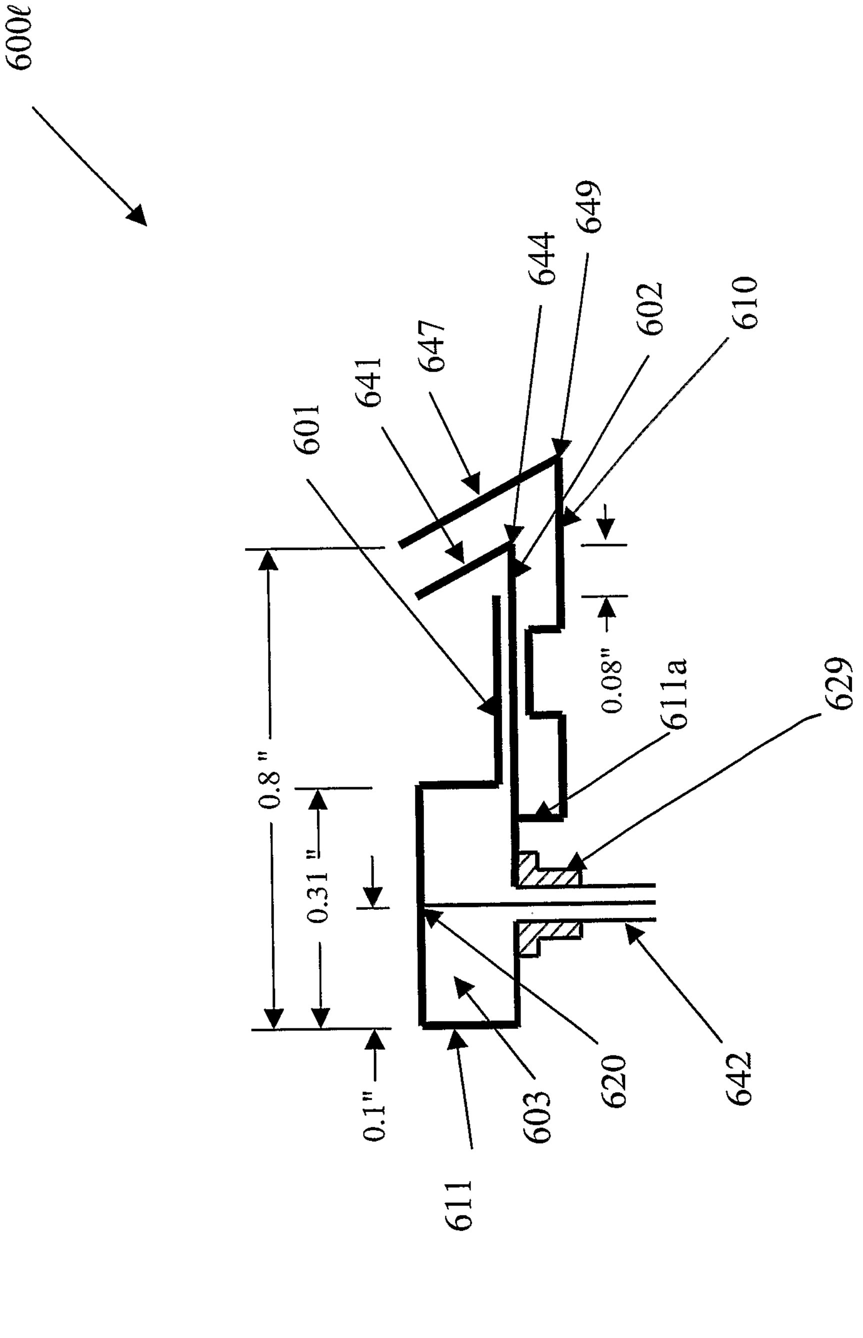

600ℓ
601
641
647
644
649
602
610
0.08"
611a
629
0.8 "
0.31 "
0.1"
611
603
620
642

FIGURE 6ℓ

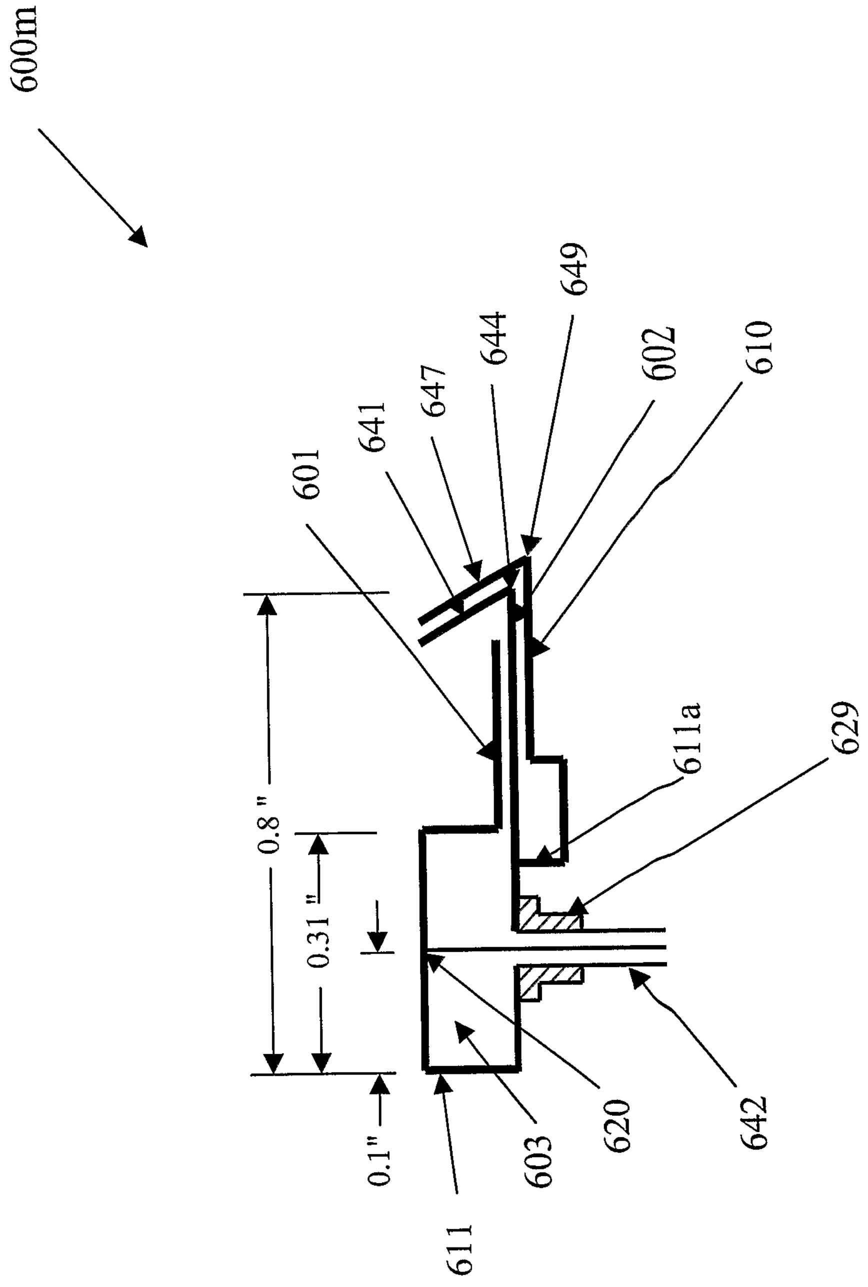

600m
649
644
647
641
601
602
610
611a
629
0.8 "
0.31 "
0.1"
611
603
620
642

FIGURE 6m

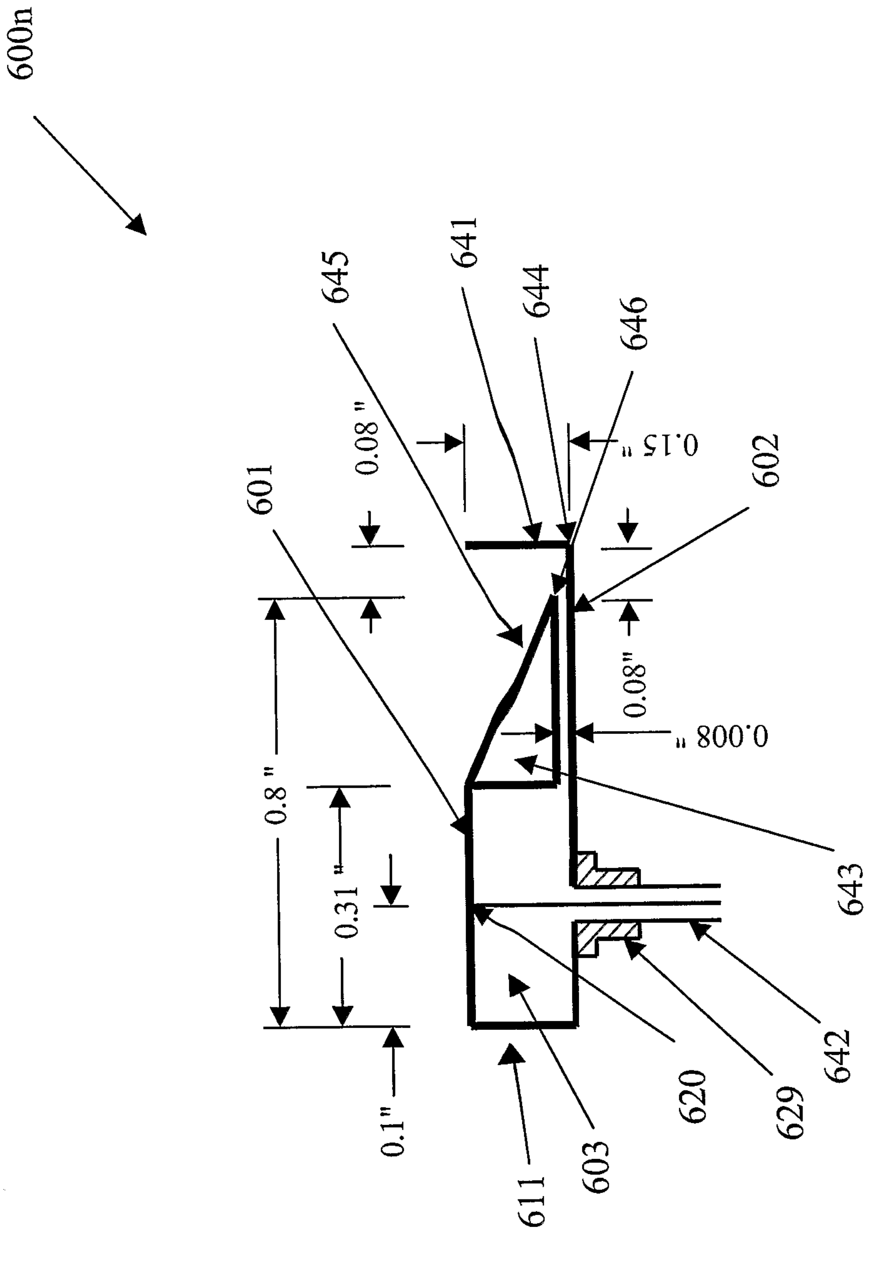

600n
645
641
644
646
0.08 "
0.15 "
601
602
0.8 "
0.31 "
0.08"
0.008 "
643
0.1"
611
603
620
629
642

FIGURE 6n

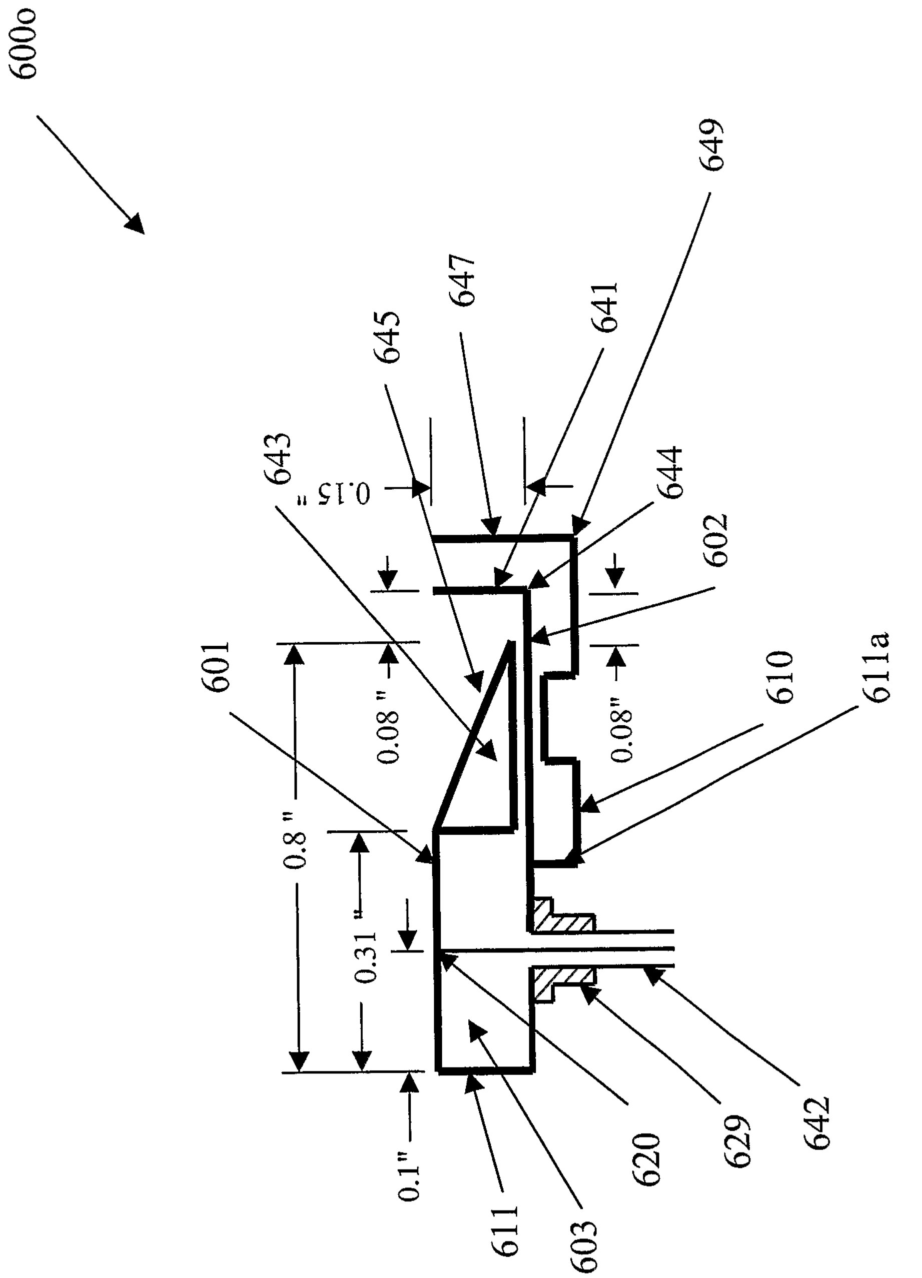

600o
649
647
641
645
643
0.15 "
644
602
601
0.08 "
0.08"
610
611a
0.8 "
0.31 "
0.1"
611
603
620
629
642

FIGURE 6o

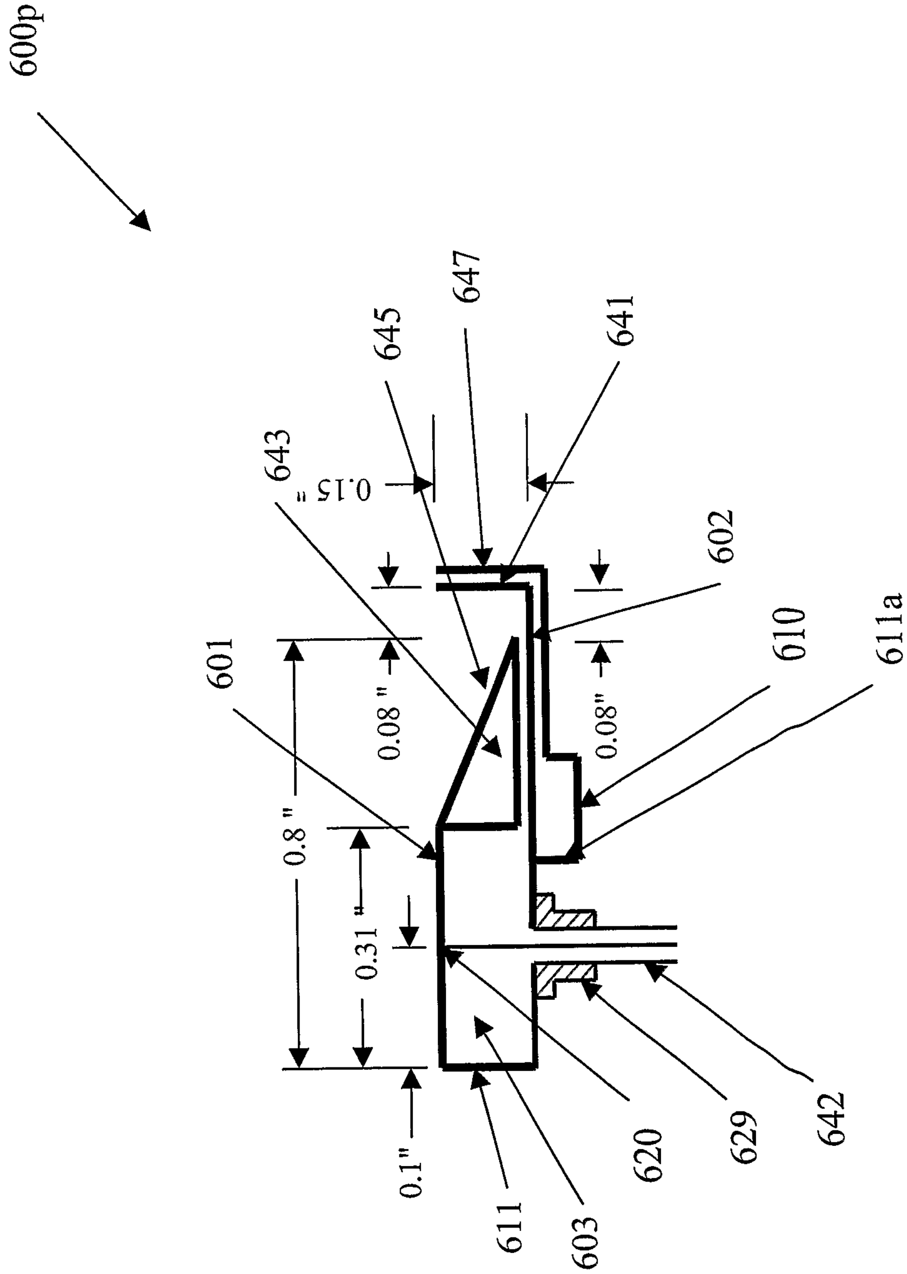

600p
647
645
641
643
0.15"
602
601
610
611a
0.08"
0.08"
0.8"
0.31"
0.1"
611
603
620
629
642

FIGURE 6p

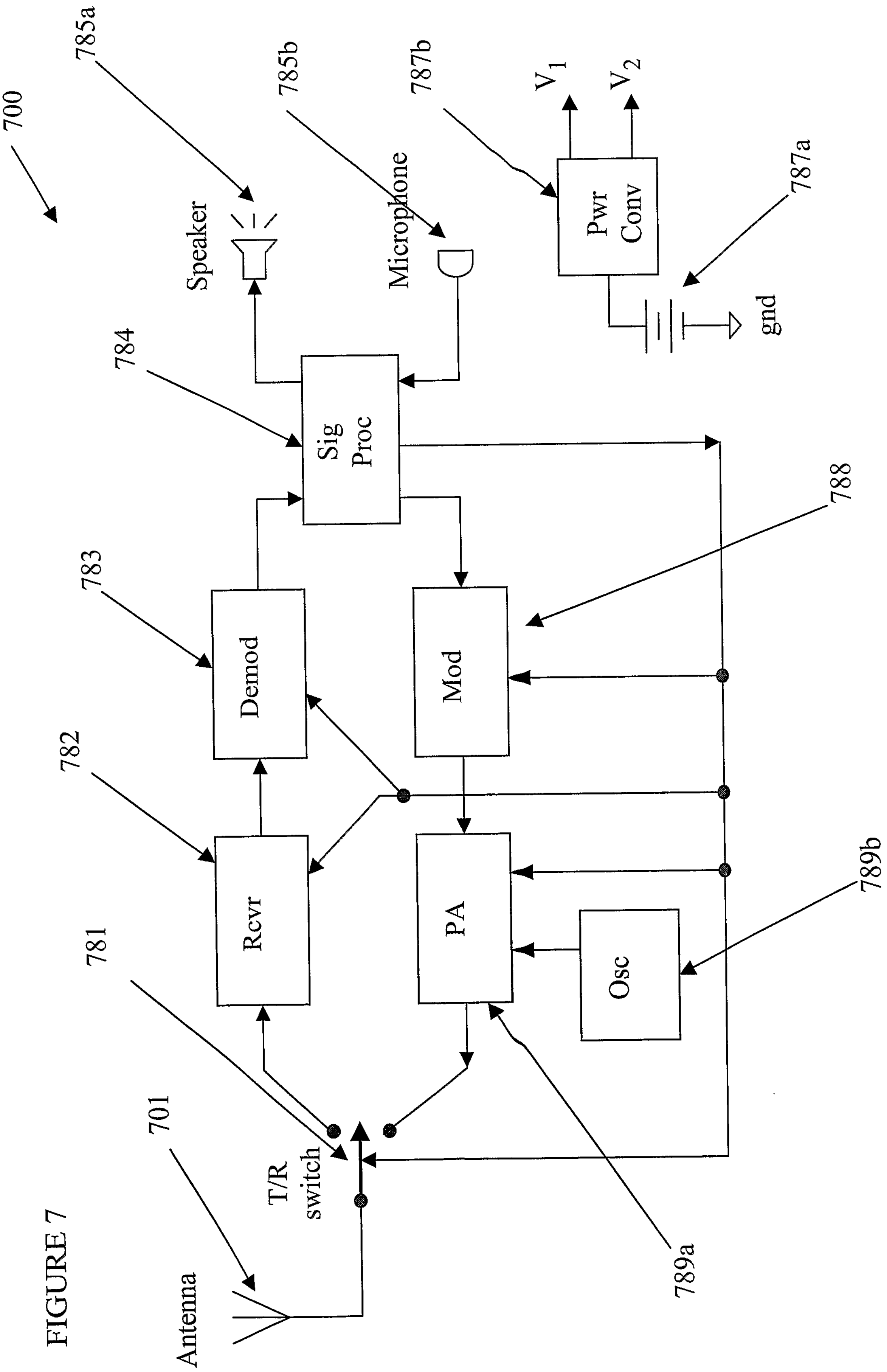

700
785a
785b
787b
V1
V2
787a
Speaker
Microphone
Pwr
Conv
gnd
784
Sig
Proc
788
783
Demod
Mod
782
Rcvr
PA
789b
Osc
781
701
T/R
switch
Antenna
789a

FIGURE 7

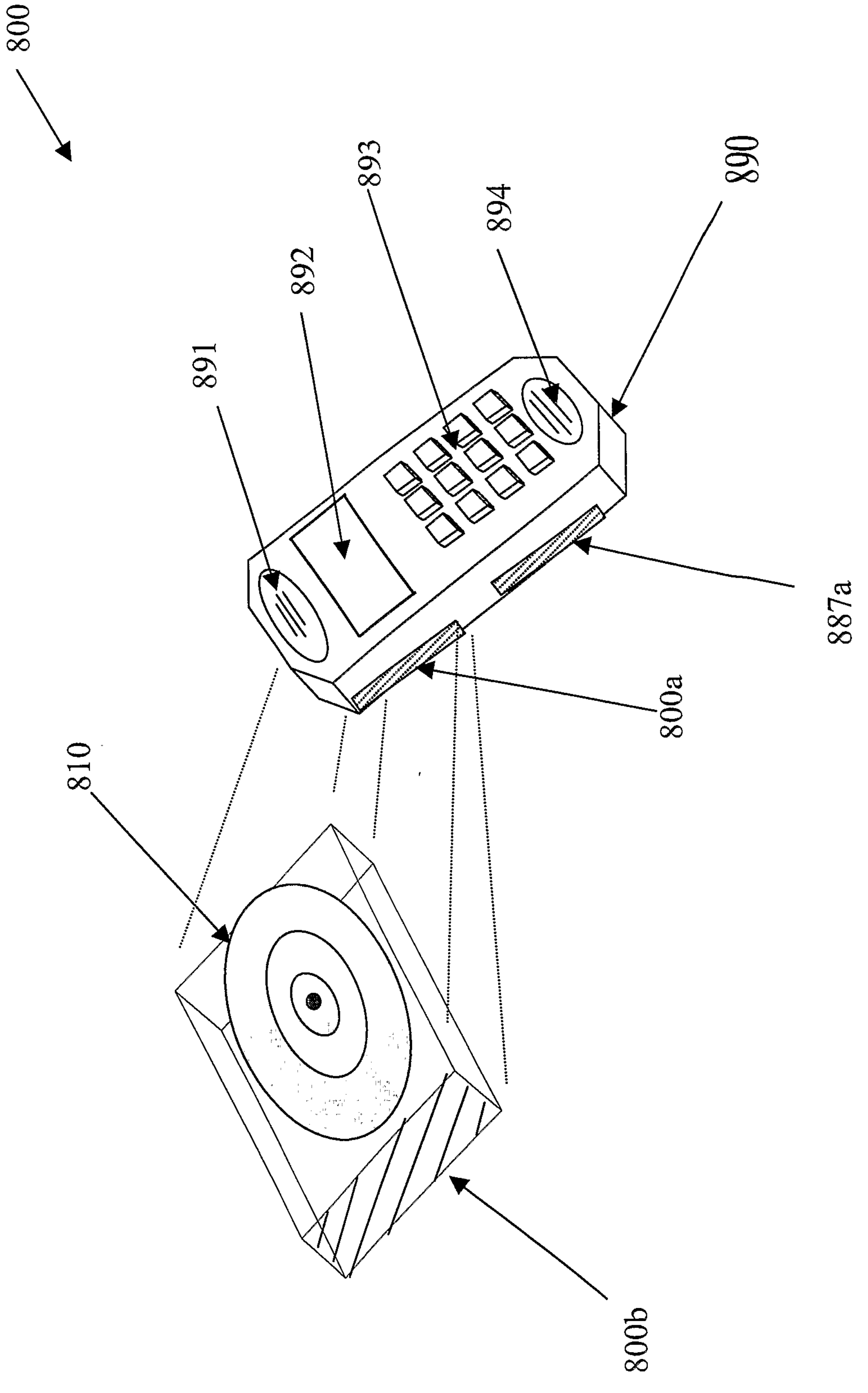


FIGURE 8