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(71) Applicant: TRUSTEES OF DARTMOUTH COLLEGE [US/US]; Hanover, NH 03755 (US).

(72) Inventors: TREMBLY, B., Stuart ; Birch Brook Road, Hanover, NH 03755 (US). HEANEY, John, A. ; Quail Road, Hanover, NH 03755 (US). DOUPLE, Evan, B. ; Rural Road #3, Box 519, Lyme, NH 03768 (US). YEH, Mark ; 43 West Wheelock Street, Hanover, NH 03755 (US). HOOPES, P., Jack ; 6 Montview Drive, Lyme, NH 03768 (US).

(74) Agents: LIEPMANN, W., Hugo et al.; Lahive & Cockfield, 60 State Street, Boston, MA 02109 (US).

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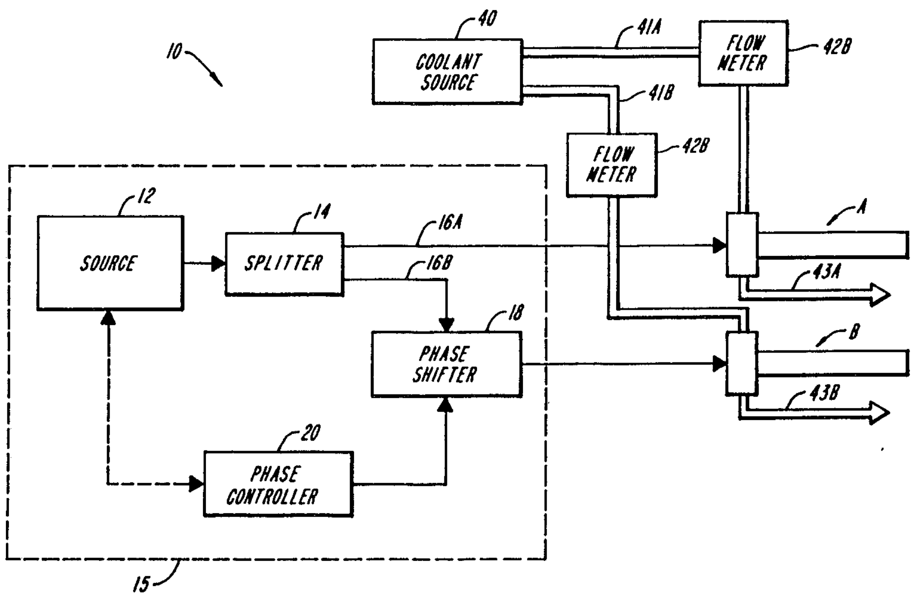

(57) Abstract

A system for hyperthermia application to human tissue comprises a catheter (43A) deployed within a naturally occurring body passage with an antenna on the catheter. The antenna is connected to a transmission line (16A) for feeding electrical current to the antenna. The system also includes another catheter (43B)/antenna/transmission line (16B) as previously described. An electrical source (15) is connected to both systems for providing alternating electrical current within a frequency range so that the antennas deposit heat producing electromagnetic energy on the human tissue. The phase of the electromagnetic energy is controlled (20) in relation to one another as to be able to control the location of electromagnetic energy deposition as to maximize the absorption of the electromagnetic energy.

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MICROWAVE HYPERTHERMIA SYSTEM AND METHOD

Background of the Invention

The invention relates generally to the field of non-surgical equipment and treatment techniques and, in particular, to such equipment and techniques used for hyperthermia treatment of the prostate.

More particularly, the invention provides an improved energy-radiating system and method for intracavity use to heat body tissue selectively.

Prostatic disease, malignant or benign, is relatively common in men over 50 years of age. More than 90% of all men develop benign prostatic hyperplasia (BPH) by the eighth decade of life. It is the most common cause of urinary obstruction in men, and 10-20% of men will require prostatic surgery at some time in their lives to relieve obstructive symptoms. Presently, the treatment of choice for symptomatic BPH is surgery. That many patients suffering from BPH are elderly and may not be candidates for surgery, however, suggests that non-surgical alternatives for therapy warrant consideration.

Non-surgical treatments for BPH include medications such as alpha-adrenergic antagonists, 5-α reductase blockers, and hormones as well as mechanical dilatation. Recently, hyperthermia has been suggested as a possible treatment for BPH. Although the precise mechanism by which hyperthermia causes cell death is not fully understood, heat is known to disrupt both the cellular membrane and nuclear function. Although the biological rationale for non-surgically treating malignant tumors with hyperthermia is not well established, clinical evidence has recently begun to suggest that hyperthermia may also be useful in the management of symptomatic BPH.

Fortunately, the anatomical location of the prostate permits various non-surgical approaches to be used for treating prostatic disease with hyperthermia. That is, intracavity approaches to the prostate are possible through both the rectum and the urethra.

Transrectal approaches for treating prostatic cancers have the advantage that the rectum can accommodate a relatively large instrument which in turn can heat a relatively large volume of tissue. Other advantages to approaching the prostate through the rectum are that most prostatic cancers lie in the posterior portion of the prostate and are therefore accessible transrectally.

Many transrectal instruments feature water cooling to prevent damage to the rectal mucosa. Water-cooled transrectal instruments deliver a maximum temperature several millimeters beneath the rectal mucosa and in the posterior prostate.

On the other hand, while transrectal hyperthermia instruments are advantageous for treating large prostatic lesions such as cancer, transurethral approaches also have significant advantages for treating BPH. For example, transurethral microwave instruments can deliver maximum temperature periurethrally and can concentrate the hyperthermia at a symptomatic lesion. Also, transurethral instruments can be easily localized within the prostate using a balloon catheter and/or imaging techniques.

One problem facing known techniques for treating the prostate with hyperthermia, however, is that when either a transrectal or a transurethral approach is selected, the inevitable shortcomings associated with that particular approach are encountered. No technique has been developed that exploits the advantages of both approaches.

Another problem is that by utilizing a single heat source deployed either transrectally or transurethrally, energy absorption is concentrated adjacent the so-deployed heat source. The known techniques do not concentrate energy absorption selectively in the prostate center.

Still another problem facing known techniques for treating the prostate with hyperthermia is that the performance of known radiating instruments, e.g. employing antennas and operating at radio or microwave frequencies, is a function of insertion depth. For optimum radiation, the antenna is to have antenna sections that are generally equal in length and that correspond to a quarter wavelength in the composite tissue/catheter medium. In typical practice, however, the length of one antenna section is dependent upon the depth to which the antenna is inserted into the patient. This insertion depth is determined by the clinical situation.

When insertion depth is not ideal based on theoretical calculations governing the operation of known transurethral microwave instruments, several problems are encountered. Antenna performance can be reduced due to increased reflected power in the antenna, which results in increased power requirements and ohmic heating of the antenna feedline. Clinically, this often results in pain for the patient, particularly at the entrance site of the catheter which the instrument employs to deploy the antenna sections. In severe situations, ohmic heating of the antenna feed-line can damage the patient's external sphincter, making it difficult or impossible for the patient to voluntarily obstruct urine flow. Another problem is that as insertion depth is changed, the impedances presented by the antenna sections become unbalanced. This causes one antenna section to radiate preferentially, and displaces the heating pattern away from the desired pattern that occurs with balanced radiation.

It is, therefore, an object of the invention to provide a microwave hyperthermia system for intracavity use that creates a substantially uniform temperature distribution pattern.

It is another object of the invention to provide such a system that delivers higher energy absorption rates than have been heretofore achievable.

Still another object of the invention is to provide a system of the above character and that exploits the benefits of both transrectal and transurethral hyperthermia treatment approaches.

Other objects of the invention will, in part, be obvious and will, in part, appear hereinafter.

Summary of the Invention

These and other objects are achieved by the present invention which features a system of hyperthermia apparatus for heating living tissue within an animal body. The system includes first and second antennas that deposit electromagnetic energy within the animal body to heat the tissue.

In one embodiment, the system includes first and second body passage catheters for deployment through first and second naturally occurring body passages, respectively. The antennas are mounted one each on each of the catheters, and are connected by transmission lines for receiving electrical current from a source.

The electrical source provides alternating electrical current within a selected frequency range to each of the first and second antennas so that the antennas radiate heat-producing electromagnetic energy within the animal body. While alternating electrical current in the microwave range, i.e. one-hundred megahertz to ten gigahertz, is preferred, electrical current within other ranges, such as radio frequency, might be desirable in various situations.

The invention further includes phasing hardware for controlling the phase of the electrical current provided to one of the antennas relative to the phase of the electrical current provided to the other of the antennas. Accordingly, the antennas cooperate to focus selectively a localized maximum heating by the electromagnetic energy and thereby attain a selectively configured local maximum specific absorption rate in the tissue.

By enabling the selective focussing of a local maximum specific absorption rate, the invention provides at least two significant benefits. The point of maximum specific absorption rate can be focussed in the tissue at one point for depositing maximum energy at that point. Also, however, the point of maximum specific absorption rate can be continually moved throughout the tissue to provide specific absorption rate in that is more uniformly distributed overall.

In one embodiment, the system features a third antenna mounted for deployment within a naturally occurring body passage and connected to a transmission line for receiving electrical current from the electrical source. The third antenna can be carried either by a third body-passage catheter or by one of the catheters used for carrying the first or second antennas. In this embodiment of the invention, the third antenna enables even higher electromagnetic absorption rates at the selected body location and with even more uniform distributions.

In still another embodiment, the invention features structure for cooling the space within the catheters and exterior to the antennas. This enables the system to effectively provide high heat levels to the living tissue while avoiding the problems associated with ohmic heating at the surfaces of the antennas and transmission lines. In one embodiment, this aspect of the invention features structure for flowing air through the catheter space exterior to the antennas. The air may be at ambient temperature or pre-cooled.

In yet another embodiment, at least one antenna is disposed eccentrically within the mounting catheter. This results in the antenna depositing electromagnetic energy preferentially from one side of the catheter.

Still another embodiment of the invention features at least one antenna having an electrical choke at a frequency within the operating range of the antenna. The choke may be formed by the antenna itself or may comprise separate components. The choke enables the antenna to deposit electromagnetic energy substantially independently of the depth to which the antenna is inserted within the animal body beyond the full insertion of the antenna.

In another aspect, the invention features a method for the spatially-controlled heating of living tissue within an animal body. A first antenna mounted on a first catheter is deployed through a naturally occurring body passage to position the antenna near the tissue to be heated. The antenna is connected to a first transmission line for feeding electrical current from a source to the antenna. A second antenna mounted on a second catheter is deployed through another naturally occurring body passage to position the second antenna near the tissue to be heated. The second antenna is also connected to a transmission line for feeding electrical current from a source to the second antenna.

In accordance with this aspect of the invention, the first and second antennas are excited with alternating electrical current within a selected frequency range so that each of the antennas deposits heat producing electromagnetic energy within the animal body. Moreover, the phase of the alternating electrical current provided to one of the antennas is controlled relative to the phase of the alternating electrical current provided to the other of the antennas, for focusing selectively a localized maximum heating by the composite electromagnetic energy deposit by the two antennas, together. In this manner, a local maximum specific absorption rate of electromagnetic energy in the tissue is attained.

Brief Description of the Drawing

These and other features of the invention will be more fully appreciated by reference to the following detailed description, which is to be read in conjunction with the attached drawing in which:

FIGURE 1 is a schematic depiction of a system of hyperthermia apparatus constructed in accordance with the present invention;

FIGURE 2 is a schematic plan view of an applicator suitable for use in connection with the system shown in FIGURE 1;

FIGURE 3 is a cross-section view taken along line 3-3 of FIGURE 2;

FIGURE 3A is a cross-section view of another embodiment of the applicator shown in FIGURE 3; and

FIGURE 4 is a schematic depiction of another embodiment of a system of hyperthermia apparatus constructed in accordance with the present invention.

Description of Illustrated Embodiment

In one aspect, schematically shown in FIGURE 1, the invention features a microwave hyperthermia system 10 including at least two intracavity applicators A and B for deployment within an animal body, such as a human, and typically by way of common or separate body cavities or passages, for depositing heat-producing electromagnetic energy into the body. The system is powered by a high-frequency power source 12. In embodiments of the invention having two applicators, a power splitter 14 is provided for dividing the alternating current from the power source 12.

As illustrated, the source current flows along transmission line paths 16A and 16B after being split by the power splitter 14. Current flowing along path 16A is provided directly to the intracavitary applicator A, for exciting the antenna of the applicator, as described in greater detail herein below, to deposit electromagnetic energy in the tissue for producing heat. Current flowing along path 16B, however, is phase shifted relative to the current flowing along path 16A, by a phase shifter 18.

If a constant phase shift is acceptable, the phase shifter 18 may consist simply of an extra length of cable or other transmission line between the power splitter 14 and the applicator B. This will delay the phase of the alternating electric current provided to applicator B with respect to the phase of alternating electric current provided to applicator A. More typically, however, it is desired to control the phase shift. Accordingly, the illustrated phase shifter 18 provides a controllable phase shift, in response to a control signal it receives from a phase shift controller 20.

In an illustrated embodiment of the system 10, the microwave power source 12 is a Holaday Model HI-915 source. The phase shifter 18 is provided by Anghel Labs of Fairfield, New Jersey. An Omni Spectra 2089-4047-00 model power splitter can be used as the power splitter 14. Those skilled in the art will understand that the source 12 and phase controller 20 can be interconnected, for example, to adjust the relative phase in conjunction with the source power level or frequency. Further, the illustrated source 12, power splitter 14, phase shifter 18 and phase controller 20 can be provided in a single controllable excitation unit 15.

A typical applicator suitable for use as either applicator A or B is shown in FIGURE 2, wherein an applicator 20 has antenna elements 22 and 24 mounted on a Foley-type catheter 26 and connected to a coaxial transmission feed line 28. The catheter 26 is arranged within an outer sheath 27. While a Foley catheter is shown, other supporting envelopes suitable for deploying the feed-line 28 and antenna elements 22 and 24 within an animal body can be used. For example, the illustrated Foley catheter is suitable for transurethral deployment.

The illustrated feed-line 28 is of the coaxial type with an inner conductor 30 and an outer conductor 32. The antenna of the illustrated applicator 20 is a form of dipole, with two radiating elements 22 and 24. The illustrated antenna elements 22 and 24 are aligned with one another and with the elongation of the catheter 26, thus forming a compact in-line structure that is easy to deploy in a body cavity or passage.

The antenna radiating elements 22 and 24 also are aligned with the coaxial transmission line 28. In particular, the illustrated element 22 employs a tubular, e.g. cylindrical, choke conductor 23 coaxially seated outwardly over the transmission line outer conductor 32 and catheter 26. The illustrated conductors 30, 32 and 23, therefore, have a substantially triaxial geometry.

The end of the choke conductor 23 distal from the source 12 (FIGURE 1) is connected to the transmission line outer conductor 32 through the wall of the catheter 26 on one side of an antenna gap 34. Accordingly, the catheter wall fills the radial gap between the transmission line conductor 32 and the antenna conductor 23. The end of the conductor 23 proximal to the source, i.e. distal from the gap 34, has no connection to the transmission line and hence is terminated with an open circuit.

This construction of the antenna element 22 forms a choke that presents a selected impedance characteristic to the feed transmission line at the antenna gap 34. As known in the art, the value of this impedance characteristic is a function of the outer diameter of the conductor 32, the inner diameter of the conductor 23, the dielectric constant of the catheter wall, the length of the conductor 23, and the frequency of operation.

The other antenna element 24 is a rod-like cylindrical conductive stub 25 that forms the other side of the antenna gap 34. The feed line inner conductor 30 extends across the gap 34, beyond the outer conductor 32, and connects to the stub 25. The outer diameter of the stub, which typically is a hollow cylindrical conductor closed at the end thereof that forms the gap 34, preferably is the same as the outer dimension of the choke conductor 23.

The width of the antenna gap 34 is a small fraction of the wavelength of the source current. The gap is large enough to ensure that there is no accidental contact between the antenna elements 22 and 24. Typically, the gap 34 is between approximately one and two millimeters.

The preferred antenna elements 22 and 24 are equal in length to form a symmetrical dipole, and are located so as to radiate over a length of four to six centimeters. For maximum flexibility, the conductors 23 and 25 can be formed from fine wire braid. A suitable wire product is manufactured by New England Electric Wire of Lisbon, New Hampshire. A suitable coaxial transmission line 28 has been found to be RG-178 coaxial cable with the outer jacket removed. When this cable is used, the antenna elements 22 and 24 are configured to present an impedance to the transmission line 28 of approximately fifty ohms. Other transmission lines known to those skilled in the art can also be used. When such other transmission lines are used, antenna elements 22 and 24 are configured to present an impedance that approximates the proper match for the selected transmission line. While coaxial cable is described and deemed preferable, persons skilled in the art may elect to employ other high frequency feed-lines.

In the illustrated embodiment shown in cross-section in FIGURE 3 the transmission line 28 passes through a drainage channel 36 in the Foley catheter 26. Connections to the antenna sections 22 and 24 are made through an exit hole made at the antenna gap 34 (FIGURE 2). As stated, the antenna section 24 is electrically connected to the inner conductor 30 of the feed-line 28 and the antenna section 22 is electrically connected to the feed-line outer conductor 32.

In use, the applicators A and B are deployed, for example, one each transrectally and transurethrally to position the antennas near a patient's prostate. With in-phase excitation of the two applicators, from the excitation unit 15, the pattern of specific absorption rate (SAR), measured in watts per kilogram, produced by the antennas is characteristically nonuniform. It has been found, however, that by delaying the driving phase of one of the antennas, a point at which the electric fields from the antennas add without cancellation can be moved to create selectively a local maximum of SAR at a selected, moveable location. This enables the delivery of maximum heating to the portion of the patient's tissue, for example the prostate, where it is most needed. It has also been found that by continually moving the selected location a more uniformly distributed SAR can be achieved.

For example, when the near surfaces of applicators A and B are separated by three centimeters in tissue-equivalent phantom material and driven at 915 MHz, experiments have shown that the local maximum of SAR is located one centimeter from the urethral applicator surface, as measured on a line connecting the two applicators. Tissue-equivalent phantom material is a substance that absorbs electromagnetic energy in the same way living tissue does. It is familiar to those practiced in the art as a means of studying the energy deposition pattern of electromagnetic applicators. When the phase of one antenna is delayed 90°, the SAR maximum shifts one centimeter toward that antenna. In this way, the phase controller can dictate what portion of, for example, the prostate will be heated without changing any other parameter of the system. An experiment with a five centimeter separation between applicator surfaces showed that a 90° phase delay of the one applicator similarly shifted the SAR maximum one centimeter toward that applicator from its position with the applicators driven in phase. This is significant, because it shows that the advantage of phase shifting can be obtained even in a cancerous prostate that is much larger than normal.

It is another feature of the invention that the structure of the antenna elements 22 and 24 be cooled during hyperthermia treatment. Since microwaves deposit power at a distance from the antenna element(s), it is possible to cool the antenna surface actively while still heating tissue located away from the antenna. Several advantage accrue from such a cooled system. For example, some hyperthermia treatments fail because the patient complains of pain at the sensitive point of insertion of the catheter. Accordingly, power must be reduced and the therapeutic benefits of the treatment lessened. Active cooling, can reduce the temperature developed at sensitive areas without reducing the amount of heat delivered to the tissue.

Another advantage of active antenna cooling is to protect the tissue membrane of the body cavity within which the antenna is deployed, such as the urethral lining or rectal mucosa. Antenna cooling enables the creation of a local temperature maximum spaced away from the antenna structure.

Accordingly, as shown in FIGURE 3, the applicator 20 also has an annular space 38 within the outer sheath 27 and exterior to the antenna surface. The system 10 of FIGURE 1 includes, therefore, a coolant source 40, and flow meters 42A and 42B for establishing and monitoring a flow of coolant through the enclosed space 38. A Cole-Parmer model DOA-104-AA coolant source is suitable for the coolant source 40, and a Fisher and Porter model 10AG130AA flow meter can be used for the flow meters 42A and 42B.

Antenna cooling can be established, therefore, by the coolant source 40 flowing coolant through flow lines 41A and 41B. From the flow lines 41A and 41B, coolant can flow out through channels 44 (FIGURE 3) and into the annular space 38. This flow path is represented in FIGURE 2 by arrows 45. The continued flow of coolant fluid in the direction of arrows 45 will cause the fluid to flow over the surfaces of the antenna elements 22 and 24 to effect the cooling thereof. Coolant is then exhausted along exhaust lines 43A and 43B (FIGURE 1).

Further, a temperature sensing device 46, such as a fibre-optic thermometry probe, is provided, for monitoring the temperature near the antenna. The temperature sensing device 46 typically is connected to communicate with other components of the system, such as the coolant source 40, the power source 12 and/or the phasing controller 20, for feed back control.

It has been found that various fluids are suitable for use as a coolant. For example, both pre-cooled and room temperature air work well. Water is also suitable. Various other acceptable coolant fluids will be apparent to those skilled in the art.

FIGURE 3A shows an applicator 20' similar to the applicator 20 except that it employs a catheter 26', upon which antenna elements are mounted, that is disposed eccentrically within an outer sheath 27. In this embodiment, therefore, the antenna elements deposit heat preferentially from one side of the sheath 27. It has been found that shifting the catheter 26 from, for example, the left-most side of sheath 27 to the right-most side of sheath 27 causes a ten fold increase in power deposition on the right side of the applicator 20. This enables heat to be focussed at, for example, a particular location in a patient's prostate.

One embodiment of the method of the invention includes the steps of deploying two antennas, one each transrectally and transurethrally, near a patient's prostate. Typically antennas so deployed are positioned approximately between three and five centimeters apart. The antennas are excited with alternating electrical current, typically within the microwave range, for example 915 MHz, so that they deposit electromagnetic energy in the patient's prostate. The phase of the electrical current provided to one antenna is shifted with respect to the phase of the electrical current provided to the other antenna. This relative phase shift attains a local maximum specific absorption rate in the tissue by selectively focusing a localized maximum heating by the electro-magnetic energy. Additionally by moving the focus point of maximum SAR, a more uniform temperature distribution can be achieved than that achieved by by driving either single antenna or by driving the two antennas in phase.

FIGURE 4 shows another embodiment of the invention wherein a third applicator C is provided. Typically, applicator C is utilized transrectally. Applicator C can be driven either at the base frequency put out by power source 12 or at a phase-delayed frequency. The phase-delayed frequency can be either that which drives applicator B or a second phase-delayed frequency. Applicator C, therefore, provides another degree of selectivity for controlling the local maximum specific absorption rate of electromagnetic energy in the tissue. Alternative to utilizing a third applicator C for carrying a third antenna, a third antenna can be mounted on either applicator A or B. That is, applicator A, for example, can be fitted with two antennas, typically spaced apart along the length of the supporting catheter and outer sheath structure.

While various embodiments of the invention have been described in detail, other alterations which will be apparent to those skilled in the art are intended to be embraced within the spirit and scope of the invention. The invention is to be defined, therefore, not by the preceeding detailed description but by the claims that follow.

Accordingly, what is claimed as new and secured by Letters Patent is:

Claims

1. A system of hyperthermia apparatus for heating living tissue within an animal body, said apparatus comprising

a first body-passage catheter for deployment through a first naturally occurring body passage,

a first antenna mounted on said first catheter for deployment within said first body passage and connected to a first transmission line for feeding electrical current from a source to said first antenna,

a second body-passage catheter for deployment through a second naturally occurring body passage,

a second antenna mounted on said second catheter for deployment within said second body passage and connected to a second transmission line for feeding electrical current from a source to said second antenna,

electrical source means connected to said first and second transmission lines for providing alternating electrical current within a selected frequency range to each of said first and second antennas so that said first and second antennas deposit heat producing electromagnetic energy within the animal body, and

phasing means for controlling the phase of the electrical current provided to one of said antennas relative to the phase of electrical current provided to the other of said antennas so that said antennas cooperate to focus selectively a localized maximum heating by said electromagnetic energy for attaining a local maximum specific absorption rate in the tissue.

2. Apparatus as set forth in claim 1, further comprising a third antenna mounted for deployment within a naturally occurring body passage and connected to a transmission line for receiving electrical current from said electrical source means.

3. Apparatus as set forth in claim 2, further comprising a third body-passage catheter for carrying said third antenna for deployment within the naturally occurring body passage.

4. Apparatus as set forth in claim 2 wherein said third antenna is mounted on said first body-passage catheter.

5. Apparatus as set forth in claim 1, further comprising means for cooling the space within said catheters and exterior of said antennas.

6. Apparatus as set forth in claim 5 wherein said means for cooling the space within said catheters and exterior to said antennas comprises means for flowing air through the space.

7. Apparatus as set forth in claim 1 wherein said first antenna is disposed eccentrically within said first catheter for radiating electromagnetic energy preferentially from one side of said first catheter.

8. Apparatus as set forth in claim 1, further comprising an electrical choke connected to at least one of said antennas, said choke being operable at an operating frequency of that antenna so that that antenna radiates electromagnetic energy substantially independently of the catheter length inserted within the animal body beyond the full insertion of that antenna.

9. A system of hyperthermia apparatus for heating a patient's prostate, the system comprising

a first catheter for transrectal deployment,

a first antenna mounted on said first catheter and connected to a first transmission line for feeding electrical current from a source to said first antenna,

a second catheter for transurethral deployment,

a second antenna mounted on a said second catheter and connected to a second transmission line for feeding electrical current from a source to said second antenna,

power source means connected to said first and second transmission lines for providing alternating electrical current within a selected frequency range to each of said first and second antennas so that said first and second antennas deposit heat producing electromagnetic energy within the patient, and phasing means for controlling the phase of the electrical current provided to one of said antennas relative to the phase of the electrical current provided to the other of said antennas so that said antennas cooperate to focus selectively a localized maximum heating by said electromagnetic energy for attaining a local maximum specific absorption rate in the tissue.

10. A system as set forth in claim 9, further comprising a third antenna mounted on a catheter for transrectal deployment, said third antenna being connected to a third transmission line for receiving electrical current from said power source means.

11. A method for heating living tissue within an animal body, said method comprising the steps of

deploying through a first naturally occurring body passage a first antenna mounted on a first catheter to position said first antenna proximal the tissue to be heated, said first antenna being connected to a first transmission line for feeding electrical current from a source to said first antenna,

deploying through a second naturally occurring body passage a second antenna mounted on a second catheter to position said second antenna proximal the tissue to be heated, said second antenna being connected to a second transmission line for feeding electrical current from a source to said second antenna, exciting each of said first and second antennas with alternating electrical current within a selected frequency range so that said first and second antennas radiate heat producing electromagnetic energy within the animal body, and

controlling the phase of the alternating electrical current provided to one of said antennas relative to the phase of the alternating electrical current provided to the other of said antennas so that said antennas cooperate to focus selectively a localized maximum heating by said electromagnetic energy for attaining a local maximum specific absorption rate in the tissue.

12. A method as set forth in claim 11 wherein said first antenna is deployed transrectally and said second antenna is deployed transurethrally to thereby position said antennas for heating a patient's prostate.

13. A method as set forth in claim 11 further comprising the step of deploying through a naturally occurring body passage a third antenna to position said third antenna proximal the tissue to be heated, and wherein said exciting step includes exciting said third antenna with alternating electrical current within the selected frequency range.

14. A method as set forth in claim 13 comprising the further step of mounting said third antenna on a third catheter.

15. A method as set forth in claim 13 comprising the further step of mounting said third antenna on said first catheter, together with said first antenna.

16. A method as set forth in claim 11 further comprising the step of cooling the space within said catheters and exterior to said antennas.

17. A method as set forth in claim 16 wherein said cooling step comprises flowing a cooling fluid through the space.

18. A method as set forth in claim 11 comprising the further step of disposing said first antenna eccentrically within said first catheter, for radiating electromagnetic energy preferentially from one side of said first catheter.

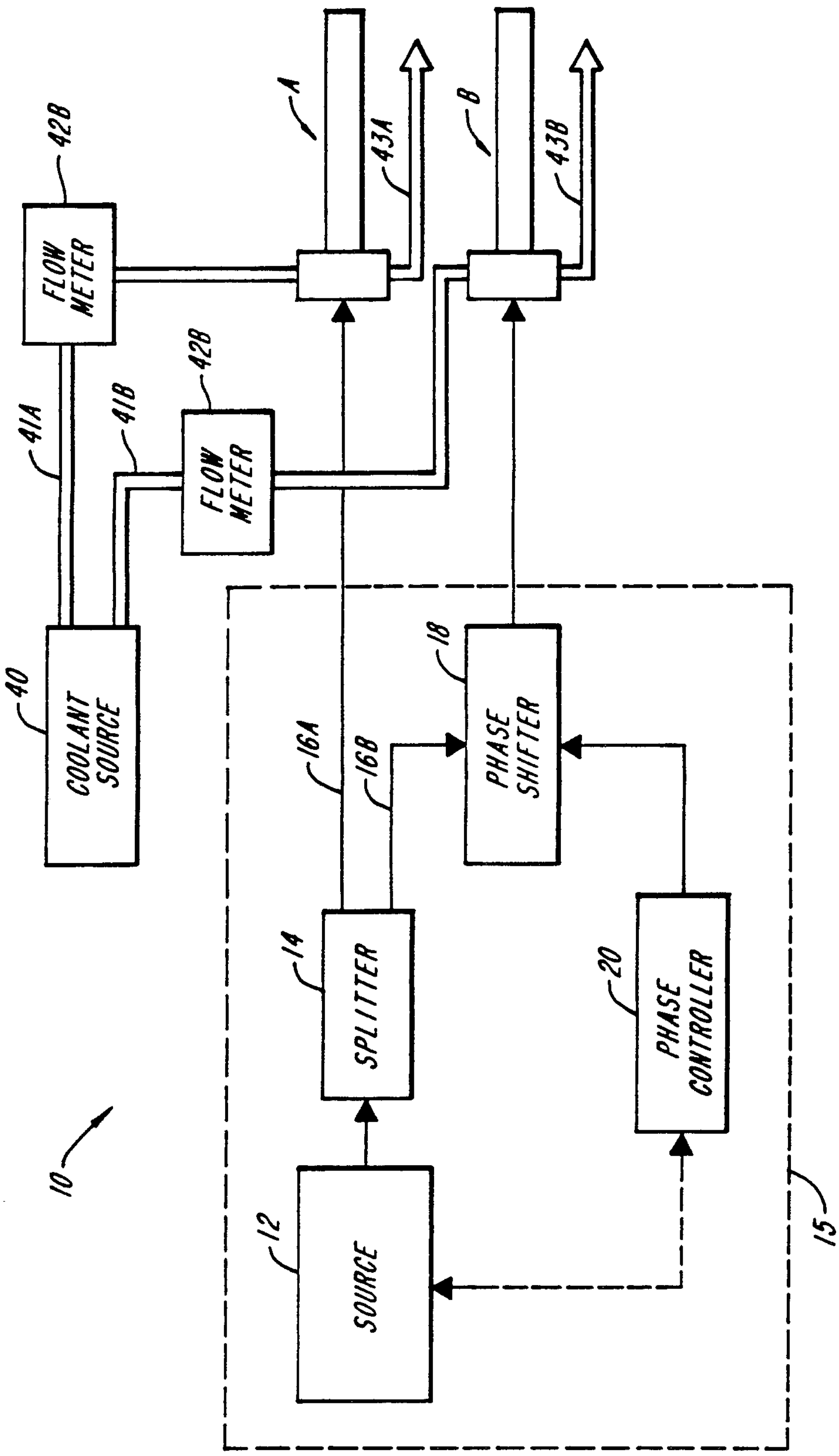

FLOW METER
42B
A
43A
B
43B
41A
41B
42B
FLOW METER
40
COOLANT SOURCE
18
PHASE SHIFTER
16A
16B
14
SPLITTER
20
PHASE CONTROLLER
10
12
SOURCE
15

FIG. 1

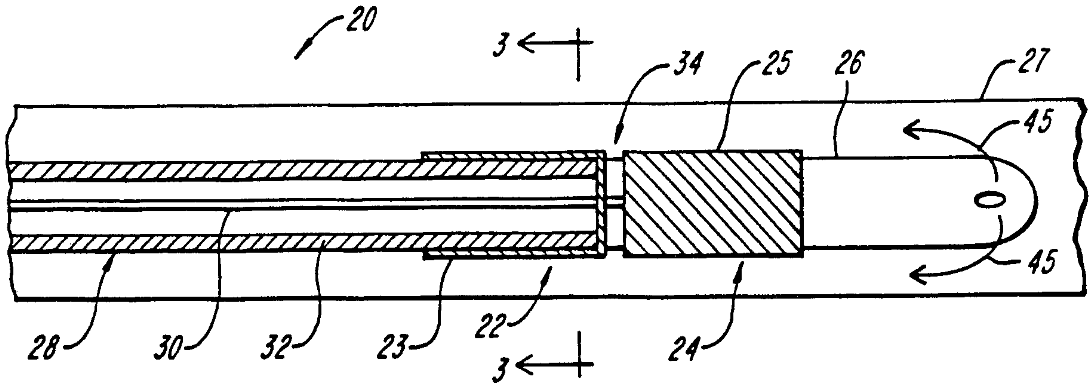


FIG. 2

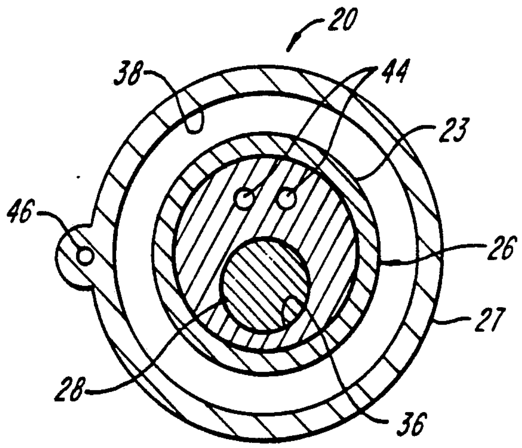


FIG. 3

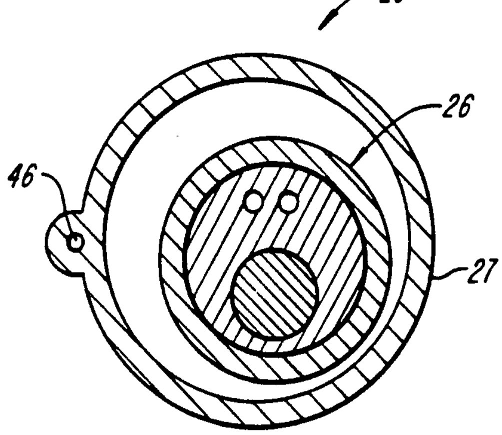
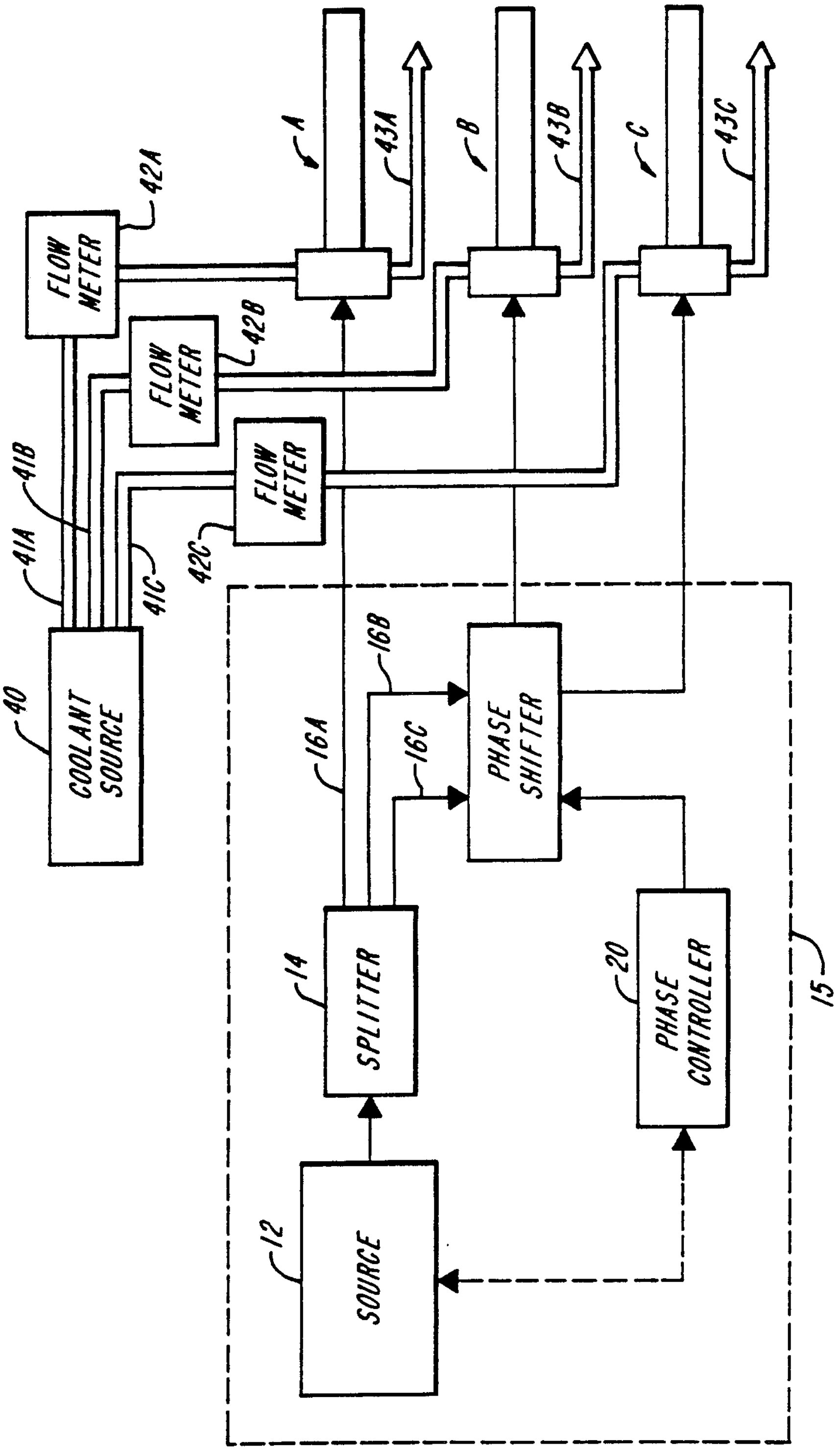


FIG. 3A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PHASE SHIFTER
14
SPLITTER
20
PHASE CONTROLLER
15
12
SOURCE

FIG. 4

INTERNATIONAL SEARCH REPORT

PCT/US92/09927

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61N 5/02
US CL :128/804
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/804 128/401,784,788; 606/32,33

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US,A, 4,732,161 (Azam et al.) 27 March 1988 See Col. 2, lines 25-58, Col. 3, lines 24-29, 48-54.	1-6,8-17 7,18
Y	US,A, 4,815,479 (Carr) 28 March 1989 See Abstract.	1-6,8-17
Y	International Journal of Hyperthermia, 15 June 1990 Trembly, Douple, Hoopes, "Air Coding of Microwave Antenna" p. 1.	5,6,16,17
Y	US,A, 4,583,589 (Kasevich) 22 April 1986 See Abstract.	8
Y	US,A, 5,007,437 (Sterzer) 16 April 1991 See Abstract.	12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 DECEMBER 1992	25 JAN 1993
Name and mailing address of the ISA/ Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer MARIANNE PARKER
Facsimile No. NOT APPLICABLE	Telephone No. (703) 308-2612

Form PCT/ISA/210 (second sheet)(July 1992)★