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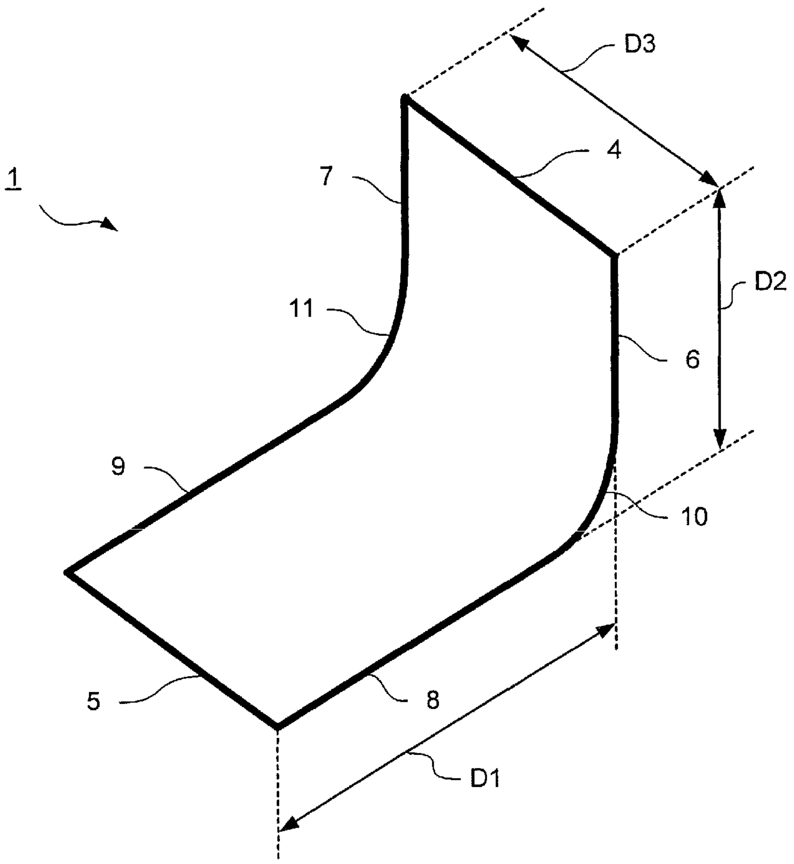
(54) Title: RF COIL FOR MR



(57) Abstract: An RF coil for MR equipment having two substantially parallel primary conductors, their respective ends connected by "J"-shaped connecting conductors.

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RF COIL FOR MR

The present invention relates to magnetic resonance (MR) equipment, both imaging and spectroscopic, and in particular to the RF coils used in such equipment.

A known MR apparatus contains the following principal components: a large magnet for producing a magnetic field, known as the B_0 field, in which the subject of interest is located; gradient coils for producing a gradient in the B_0 field; RF coils for producing an additional magnetic field, known as the B_1 field, which is used to rotate the spin of the nuclei in the subject of interest by appropriate flip angles and for detecting the signal from the spins within the subject of interest; and a control system for setting the gradient fields, producing the RF pulses transmitted by the RF coils and for receiving and processing the signals received by the RF coils.

The apparatus may use RF coils which both transmit RF pulses and receive the signals. Alternatively, the apparatus may have different RF coils for performing both these functions. In general, there are two types: surface coils, which are placed on top of the subject of interest, and volume coils, which are used with the subject of interest located within them.

Conventional MR surface coil technology is based on the use of planar loop coils where the "sweet spot" of the coil is generally not used for signal excitation or detection. The "sweet spot" is defined as the region at the centre of the coil where the magnetic field homogeneity (% variation over a specified volume) is at a maximum and where adequate sensitivity exists for MR signal excitation and detection. However, for deep organ applications such as cardiac MR, the "sweet spot" of conventional surface coils is remote from the region of interest (ROI) and, consequently, the homogeneity benefits afforded by the "sweet spot" are not utilised.

Deep organ MR requires maximised sensitivity and magnetic field homogeneity over a relatively large field of view (FOV). However it is not possible to maximise both sensitivity and magnetic field homogeneity simultaneously. One can maximise the sensitivity by minimising the coil volume, but this reduces the magnetic field homogeneity. Conversely, one can maximise the magnetic field homogeneity by increasing the coil volume, but this reduces sensitivity. The conventional approach to address this problem has been the Phased-Array coil, which is an array of closely packed surface coils that offer the sensitivity benefit of a surface coil, and the FOV benefit of a volume coil. However, this approach requires a separate RF transmitter coil and an MR scanner with multiple receiver channels. This significantly increases the complexity of the scanner and consequently greatly increases its cost.

It is therefore an object of the present invention to provide a coil design that is appropriate for deep organ MR applications, especially cardiac MR, without greatly increasing the complexity and cost of the MR scanner.

According to the present invention there is provided an RF coil for use with magnetic resonance equipment comprising

first and second, substantially parallel, primary conductors, the respective ends of which are connected by two connecting conductors; wherein:

the connecting conductors each have a first section that is substantially perpendicular to a second section; said first sections are substantially parallel and extend from and are substantially perpendicular to the first primary conductors; and said second sections extend from and are substantially perpendicular to the second primary conductor.

An RF coil of this configuration increases the available "sweet spot" of the coil to deep lying ROIs, facilitating imaging and spectroscopy of elements deep within the subject of interest using MR scanners that are only equipped to use a single coil.

Preferably, the primary conductors are between 190 and 260 mm in length, are separated, in a direction parallel to the first sections of the connecting conductors, by between 260 and 350 mm, and are separated, in a direction parallel to the second sections of the connecting conductors, by between 190 and 260 mm. A coil of these dimensions is optimal for cardiac imaging of adult humans.

By connecting the first and second sections of the connecting conductors by curved sections, preferably with a radius of curvature of between 100 and 130 mm, the coil can be fitted more closely to the human torso, improving the results of the MR scanner.

The coil of the present invention produces a region, the "sweet spot", in which the sensitivity and homogeneity are both above respective predetermined thresholds. At least part of this region is located displaced from a plane defined by the first primary conductor and the first section of the connecting conductors in a direction towards the second primary conductor and displaced from the plane defined by the second primary conductor and the second sections of the connecting conductors in a direction towards the first primary conductor. This ensures that the "sweet spot" is in proximity to the region of interest which may, for example, be the heart in a human body or another deep organ.

The present invention also provides magnetic resonance equipment incorporating means of producing the B_0 magnetic field, a control system for generating sets of RF pulses and for processing the signals detected from an object being studied with the magnetic resonance equipment and an RF coil as described above. The equipment may use the RF coil for transmitting the sets of RF pulses and/or detecting the signals from the object being studied. It is advantageous for the equipment to be able to use the RF coil for both transmitting RF pulses and detecting signals since it reduces the complexity of the apparatus and hence its cost.

Furthermore the magnetic resonance equipment of the present invention may be used for imaging and/or spectroscopy. The dual functionality of the equipment makes its use more cost effective.

The present invention also provides a method of analysing a body using magnetic resonance; said method comprising the step of arranging an RF coil, as described above, adjacent to the body such that at least part of the body is located in a space between a plane defined by said first primary conductor and said first sections of said connecting conductors and a parallel plane in which the second primary conductor is located; said space also between a plane defined by said second primary conductor and said second sections of said connecting conductors and a parallel plane in which the first primary conductor is located.

Furthermore, the present invention also provides a method of manufacturing an RF coil for magnetic resonance equipment as described above, wherein the designing step comprises:

selecting the approximate dimensions of a coil such that, when the coil is placed on a body, an organ of interest within the body is substantially equidistant from the first and second primary conductors and such that the lengths of the primary conductors is slightly longer than the organ of interest; and

optimising the dimensions of the RF coil to maximise the homogeneity in the region of the organ of interest.

The present invention will now be described by way of non-limiting example with reference to the accompanying Figures, in which:

Fig. 1 represents an RF coil of the present invention;

Fig. 2 depicts an RF coil of the present invention adjacent to a human torso; and

Fig. 3 depicts a conventional RF coil adjacent to a human torso.

Figure 1 shows the RF coil 1 according to the present invention. It is comprised of primary conductors 4, 5 which are substantially parallel. The primary conductors 4, 5 are connected by connecting conductors. A first connecting part 6, 7 of each connecting conductor is attached at either end and extend substantially perpendicularly from the first conductor 4. Second connecting parts 8, 9 of the connecting conductors are connected at either end of and extend substantially perpendicularly from the second primary conductor 5. The first connecting parts 6, 7 are substantially mutually parallel and are perpendicular to the second connecting parts 8, 9 which are also substantially mutually parallel. Curved sections 10, 11 connect the first and second parts of the first and second connecting conductors, respectively. The resulting coil, when viewed in a direction parallel to the primary conductors 4, 5, is "J" or "L"-shaped.

Figure 2 shows the RF coil 1, in cross-section, adjacent to a human torso 23. A target region of interest (Target ROI) 24 is identified within the human torso. The primary conductors 4, 5 are located such that the Target ROI 24 is located on a line between them and substantially equidistant from them. In addition, the primary conductors 4, 5 are located more than a set distance from the torso 23 to provide room for padding. The length of the primary conductors 4, 5 is set to be slightly longer than the object of interest. This provides a reasonable compromise between sensitivity and magnetic field homogeneity and allows for some error in the positioning of the coil on the subject of interest.

For a typical person with a height of about 1.8 metres and mass 70-75 kg, it has been found that, when the Target ROI is the heart, appropriate dimensions for the coil are approximately 260 to 350 mm for the distance D1 between the primary conductors 4, 5 in a direction parallel to the second parts 8, 9 of the connecting conductors; approximately 190 to 260 mm for the distance D2 between the primary conductors 4, 5 in a direction parallel to the first parts 6, 7 of the connecting conductors; and approximately 190 to 260 mm for the length D3 of the primary conductors 4, 5. Furthermore, to facilitate close fitting of the coil to the torso, it has been found that the radius of curvature of the curved sections 10, 11 of the connecting conductors should be between about 100 and 130 mm.

Within these dimensions, the design of the coil can be optimised using transmission line modelling to evaluate the performance of the RF coil, namely optimising the location of the "sweet spot". An iterative process may be used, setting the dimensions of a proposed RF coil, evaluating its performance, altering the dimensions of the proposed coil and evaluating the effect on the performance of the amendments.

For a coil of the present invention, an optimised embodiment was found to have a "sweet spot" with the following parameters. The sensitivity (the time taken to achieve a 90° flip angle from a region of interest for a specified power level) was found to be 700μs for a 1kW rectangular pulse for the Target ROI 24. The magnetic field homogeneity (percentage variation of magnetic field intensity over a specified volume) was found to be ±10% over a 50 mm x 50 mm x 50 mm volume (representing the left position wall of the heart) centred at the Target ROI 24.

A comparison of Figures 2 and 3, which show the coil 1 of the present invention and a conventional coil 30, respectively, adjacent to a torso 23 clearly demonstrates the benefits of the present invention. The torso 23 has three distinct regions. The first region 20 is the area that produces the signal that it is intended to study, namely a signal from the heart, for example. The second region 21 contains the lungs and bone and produces very little MR signal. The third region 22 contains skeletal muscle and subcutaneous fat which produces a strong MR signal that it is not intended to study. As shown, the sweet spot 23 of the coil 1 of the present invention encompasses a large part of the region 20 that is being studied, facilitating its study. By contrast, the sweet spot 31 of the conventional surface oil 30 does not coincide with any of the region 20 to be studied and therefore it is difficult to study this region.

Although the above description describes in detail the configuration of a coil for studying the human heart, it will be appreciated that the present invention may also be used for coils for studying other deep organs in the human body and objects embedded within other subjects of interest. For instance, coils may be designed for use with the liver, kidney, hip and pelvis.

The coil of the present invention may also be used with other coils, for example to perform so-called dual coil MR. This has application for ^{1}H magnetic Resonance Imaging (MRI) and ^{31}P Magnetic Resonance Spectroscopy (MRS), where the conformal surface coil is used for locating the heart and ^{1}H decoupling of the ^{31}P resonance for improved MRS sensitivity. Also, ^{1}H MRI and ^{23}Na MRI and ^{1}H MRI and ^{1}H MRS of the heart is possible. These dual coil MR applications would require a minimum of modification to be implemented on a conventional MR scanner. The coil may also be used in a Phased-Array where enhanced sensitivity and magnetic field homogeneity are required.

The coil may be used for transmitting RF pulses, for detecting signals from the object being studied or as a coil for doing both. Furthermore, the coil is appropriate for use with both MR imaging and MR spectroscopy.

CLAIMS

1. An RF coil for use with magnetic resonance equipment comprising

first and second, substantially parallel, primary conductors, the respective ends of which are connected by two connecting conductors; wherein:

the connecting conductors each have a first section that is substantially perpendicular to a second section; said first sections are substantially parallel and extend from and are substantially perpendicular to the first primary conductors; and said second sections extend from and are substantially perpendicular to the second primary conductor.

2. An RF coil for use with magnetic resonance equipment according to claim 1, wherein the primary conductors are between 190 and 260 mm in length.

3. An RF coil for use with magnetic resonance equipment according to claim 1 or 2, wherein said primary conductors are between 260 and 350 mm apart in a direction parallel to said first sections of the connecting conductors.

4. An RF coil for use with magnetic resonance equipment according to claim 1, 2 or 3, wherein said primary conductors are between 190 and 260 mm apart in a direction parallel to said second sections of the connecting conductors.

5. An RF coil for use with magnetic resonance equipment according to claims 1 to 4, wherein said first and second sections are connected by curved sections of the connecting conductors.

6. An RF coil for use with magnetic resonance equipment according to claim 5, wherein said curved sections have a radius of curvature of between 100 and 130 mm.

7. An RF coil for use with magnetic resonance equipment according to any preceding claim, wherein the coil, when viewed in a direction parallel to the primary

conductors is substantially "L" or "J"-shaped.

8. An RF coil for use with magnetic resonance equipment according to any preceding claim, wherein the coil produces a region in which the sensitivity and homogeneity are both above respective predetermined thresholds; and

at least part of said region is located displaced from the plane defined by said first primary conductor and said first section of the connecting conductors in a direction towards the second primary conductor; and displaced from the plane defined by said second primary conductor and said second sections of the connecting conductors in a direction towards the first primary conductor.

9. Magnetic resonance equipment comprising:

means for producing the B_0 magnetic field;

a control system for generating sets of RF pulses and for processing the signals detected from an object being studied with the magnetic resonance equipment; and

an RF coil according to any one of the preceding claims.

10. Magnetic resonance equipment according to claim 9, wherein said RF coil is used for transmitting said sets of RF pulses.

11. Magnetic resonance equipment according to claim 9 or 10, wherein said RF coil is used for detecting said signals from the object being studied.

12. Magnetic resonance equipment according to claim 9, 10 or 11, wherein said magnetic resonance equipment is used for imaging.

13. Magnetic resonance equipment according to any one of claims 9 to 12, wherein said magnetic resonance equipment is used for spectroscopy.

14. A method of analyzing a body using magnetic resonance; said method

comprising the step of arranging an RF coil according to any one of claims 1 to 8 adjacent to the body such that at least part of the body is located in a space between a plane defined by said first primary conductor and said first sections of said connecting conductors and a parallel plane in which the second primary conductor is located; said space also between a plane defined by said second primary conductor and said second sections of said connecting conductors and a parallel plane in which the first primary conductor is located.

15. A method of analyzing a body according to claim 14, wherein said method further comprises transmitting a series of RF pulses using said RF coil in said arrangement.

16. A method of analyzing a body according to claim 14 or 15, wherein said method further comprises using said RF coil in said arrangement to detect signals from said body in response to a series of RF pulses.

17. A method of analyzing a body according to claim 14, 15 or 16, wherein said body is a human body and said RF coil is according to claim 8; and wherein said step of arranging the RF coil is such that at least part of the heart is located in said region in which the sensitivity and homogeneity are maximized.

18. A method of analyzing a body according to any one of claims 14 to 17, wherein the analysis is imaging.

19. A method of analyzing a body according to any one of claims 14 to 17, wherein the analysis is spectroscopy.

20. A method of manufacturing an RF coil for magnetic resonance equipment, comprising:

designing an RF coil according to any one of claims 1 to 8, and manufacturing the coil according to the design.

21. A method of manufacturing an RF coil for magnetic resonance equipment according to claim 20, wherein the designing step comprises:

selecting the approximate dimensions of a coil such that, when the coil is placed on a body, an organ of interest within the body is substantially equidistant from the first and second primary conductors and such that the lengths of the primary conductors is slightly longer than the organ of interest; and

optimizing the dimensions of the RF coil to maximize the homogeneity in the region of the organ of interest.

22. A method of manufacturing an RF coil for magnetic resonance equipment according to claim 21, wherein the dimensions of the RF coil are optimized using transmission line modeling to evaluate the performance of RF coils with contemplated dimensions.

23. A method of manufacturing an RF coil for magnetic resonance equipment according to claim 21 or 22, wherein the organ of interest is the heart.

Fig. 1

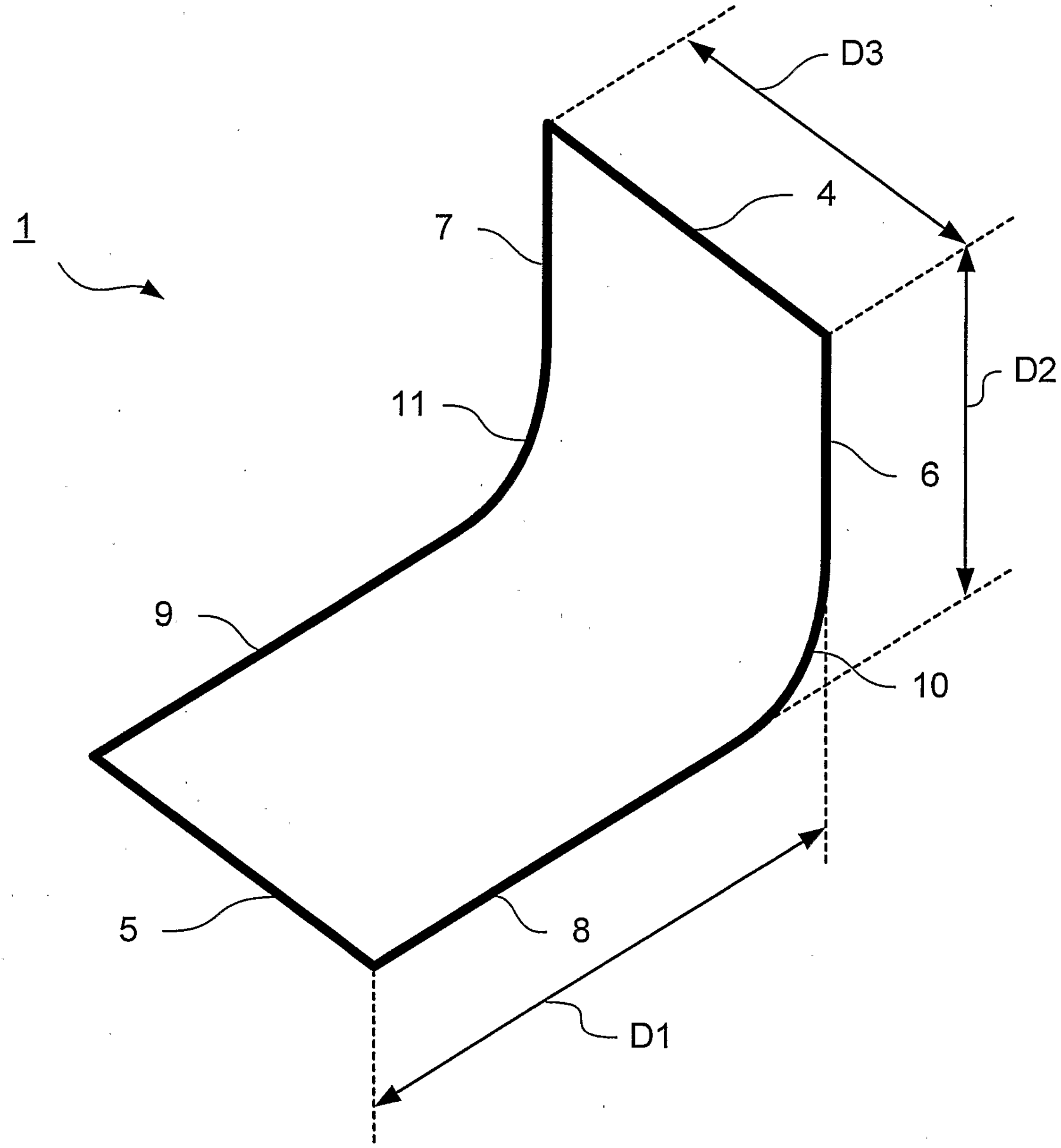


Fig. 2

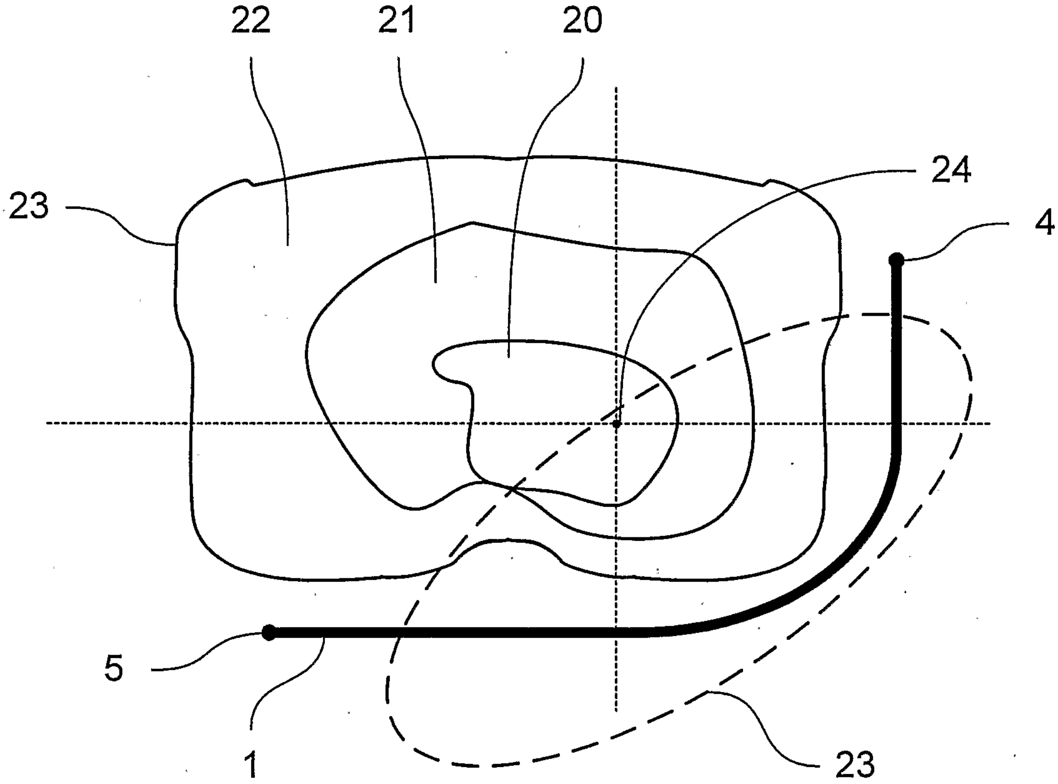
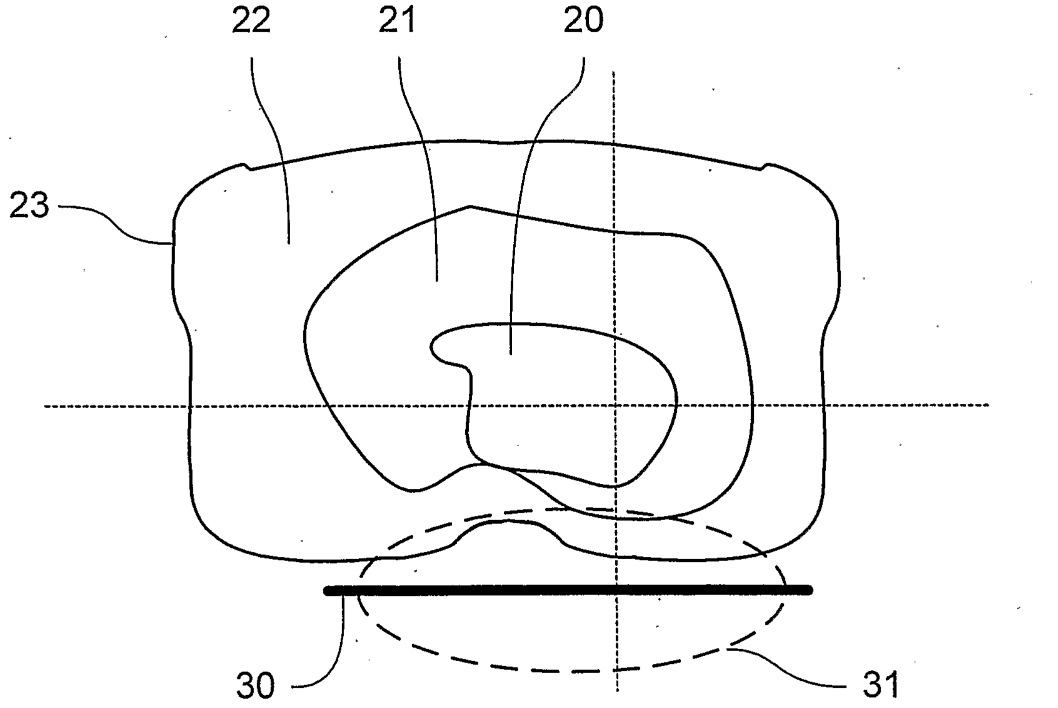


Fig. 3



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 03/04048

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01R33/341

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)
IPC 7 G01R

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 practical, search terms used)

PAJ, EPO-Internal, INSPEC, COMPENDEX, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 076 (C-0914), 25 February 1992 (1992-02-25) -& JP 03 267045 A (TOSHIBA CORP;OTHERS: 01), 27 November 1991 (1991-11-27) see figs. 1 and 5 and the abstract	1-22
X	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 06, 30 April 1998 (1998-04-30) -& JP 10 033496 A (SHIMADZU CORP), 10 February 1998 (1998-02-10) abstract	1-22
X	JP 63 065850 A (HITACHI MEDICAL CORP) 24 March 1988 (1988-03-24) figure 5	1-23

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lersch, W

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PCT/GB 03/04048

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0 753 758 A (PICKER INT INC) 15 January 1997 (1997-01-15) column 8, line 15 -column 8, line 31; figures 10E,11B -----	1-23

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Internatio[redacted]pplication No
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