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File Number: T 224/91 - 3.4.2

Application No.: 83 102 875.8

Publication No.: 0 091 008

Title of invention: Method of three-dimensional NMR imaging using selective excitation

Classification: G01N 24/08

D E C I S I O N
of 6 November 1991

Proprietor of the patent: General Electric Company

Opponent: Siemens AG

Headword:

EPC Art. 56

Keyword: "Inventive step (yes)"

Headnote



Case Number : T 224/91 - 3.4.2

D E C I S I O N
of the Technical Board of Appeal 3.4.2
of 6 November 1991

Appellant :
(Opponent)

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Respondent :
(Proprietor of the patent)

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Representative :

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Decision under appeal :

**Decision of Opposition Division of the European
Patent Office dated 8 November 1990 and posted on
17 January 1991 rejecting the opposition filed
against European patent No. 0 091 008 pursuant to
Article 102(2) EPC.**

Composition of the Board :

Chairman : W. Hofmann
Members : C. Black
C. Payraudeau

Summary of Facts and Submissions

- I. European patent No. 0 091 008 was granted on the basis of European patent application No. 83 102 875.8.
- II. An opposition was filed against the European patent by the Appellant.

During the opposition procedure, the Appellant cited the documents

(D1) DE-A-2 611 497,

(D₂*) EP-B1-0 046 782 (not prepublished, whereas the corresponding document EP-A-0 046 782 (& WO-A-81/02788) belongs to the state of the art pursuant to Article 54(2) EPC),

(D3) DE-A-2 936 465, and

(D4) GB-A-2 079 463.

- III. The Opposition Division decided to reject the opposition.
- IV. An appeal was lodged against the decision of the Opposition Division. In the statement of grounds, the Appellant (Opponent) cited the further documents

(D2) EP-A-0 046 782 (in place of (D₂*))

(D5) Journal of Magnetic Resonance, Vol. 29 (1978), pag. 355-373, P. Mansfiel et al., "Biological and medical imaging by NMR",

(D6) US-A-4 165 479, and

(D7) I.E.E.E. Spectrum, Vol. 20 (1983), No. 2, pag. 32-38, P.A. Bottomley, "Nuclear magnetic resonance: beyond physical imaging" (not prepublished).

- V. The Respondent (Patentee) referred to documents D5 to D7 and five further documents in support of his arguments.
- VI. Oral proceedings were held, at the end of which the Appellant requested that the decision of the Opposition Division be set aside and the patent be revoked. The Respondent requested that the appeal be dismissed and the patent maintained as granted
- VII. Claim 1 reads as follows:

"A method of NMR imaging in which selective excitation is used to excite a thick planar slab of nuclear spins in an imaging sample situated in a static magnetic field said method comprising the steps of:

- a. applying for a first predetermined time interval a magnetic field gradient along a first axis of said imaging sample;
- b. irradiating said sample, during said first time interval, with a frequency selective RF pulse so as to excite a plurality of nuclear spins in said thick planar slab of said imaging sample such that a thick planar slab is selected to be situated within the region over which the receiver coil for detecting NMR signals is sensitive;
- c. applying during a second predetermined time interval, subsequent to said first time interval:
 - (1) a first magnetic field gradient directed along said first axis for phase encoding nuclear spin spatial distribution information along said first axis, said first magnetic field gradient having a predetermined amplitude selected from n_z different amplitudes, wherein n_z is equal to the number of said tomographic section images and is greater than 1,

- (2) a second magnetic field gradient directed along a second axis of said imaging sample for dephasing said excited nuclear spins, and
 - (3) a third magnetic field gradient directed along a third axis of said imaging sample, said third axis being orthogonal to said second axis, for phase encoding nuclear spin spatial information along said third axis, said third magnetic field gradient having a predetermined amplitude selected from n_y different amplitudes, wherein n_y is equal to the number of pixels in one of said tomographic section images along said third axis;
- d. applying, during a third predetermined time interval, subsequent to said second time interval, a rephasing magnetic field gradient having the same direction as said second magnetic field gradient, so as to rephase said nuclear spins dephased during said second time interval to produce a spin echo signal, the Fourier transform of which is a projection of nuclear spin spatial distribution information from throughout said thick planar slab onto said second axis;
 - e. sampling said spin echo signal n_x times in the presence of said rephasing magnetic field gradient, wherein n_x is equal to the number of pixels in one of said tomographic section images along said second axis;
 - f. repeating the preceding steps for n_y different amplitudes of said third magnetic field gradient; and
 - g. repeating the preceding steps for n_z different amplitudes of said first magnetic field gradient,

h. whereby the necessary three-dimensional imaging information for constructing a series of tomographic section images of said thick planar slab is collected simultaneously from throughout said thick planar slab."

Formally independent Claims 11 and 26 include all the steps of Claim 1. They can thus actually be regarded as dependent claims. Remaining claims 2 to 10, 12 to 25 and 27 to 30 are dependent on Claims 1, 11 and 26, respectively.

VIII. In support of his request, the Appellant argued essentially as follows.

Document D2 refers to a two-dimensional spin-warp NMR imaging method, in which nuclear spins in a plane are selectively excited, a phase encoding gradient and a read out gradient are applied along two orthogonal axes in said plane and a complete planar image is reconstructed by two-dimensional Fourier transformation of the recorded signals.

Document D1 shows three-dimensional NMR Fourier zeugmatography, in which spins in a sample are excited by a nonselective rf pulse, two phase encoding gradients and a read out gradient are applied along three mutually orthogonal axes and an image is reconstructed using a three-dimensional Fourier transform.

Considering that document D1 is acknowledged in the description of D2 and that the object of the patent in suit is to provide a three-dimensional NMR imaging method, it is obvious to a skilled man to apply the measure of two phase encoding gradients along two orthogonal axes, as known from D1, to the method according to D2 in order to

achieve said object. Therefore, the combination of documents D2 and D1 deprives the subject-matter of Claim 1 of an inventive step.

Furthermore, as regards the Claims 11 and 26, they refer to methods which essentially differ from the subject-matter of Claim 1 in that in Claim 11 a π rf pulse is used to generate a composite spin echo, this measure being already known from D3, and in Claim 26 the signal is observed during repeated switching of the gradient for generating an echo train, this measure being known from D4. The subject-matter of Claims 11 and 26 is therefore obvious.

IX. The Respondent substantially argued as follows.

Claims 1, 11 and 26 refer to a method of NMR 3D imaging and contain the steps of exciting the nuclear spins in a thick planar slab of the imaging sample orthogonal to a given axis by means of a frequency selective $\pi/2$ rf pulse and then selecting a plurality of tomographic section images of said thick planar slab by phase encoding nuclear spin spatial distribution information along said axis. Although selective excitation as well as phase encoding are known as such, an inventive step is seen in this combined use of the two localisation techniques, i.e. selective excitation and phase encoding, in the same direction, a combination which is not hinted at by the cited prior art.

On the contrary, the prior art shows the existence of a prejudice against the use of selective excitation and phase encoding along the same direction, which were regarded as mutually excluding alternatives towards the same end. In the patent in suit, which describes the synergistic simultaneous use of said two techniques, the prejudice is overcome for the first time.

Reasons for the Decision

1. The appeal is admissible.

2. Novelty

2.1 Document D2 refers to a two-dimensional spin-warp NMR imaging method comprising the following steps (see the Figure):

- subjecting an imaging sample to a static magnetic field along an axis of said sample;
- applying for a first predetermined time interval a magnetic field gradient along a first axis y of said imaging sample;
- irradiating said sample, during said first time interval, with a frequency selective $\pi/2$ rf pulse so as to excite a plurality of nuclear spins in a given plane orthogonal to said first axis y, said plane being selected to be situated within the region over which the receiver coil for detecting NMR signals is sensitive;
- reversing said magnetic field gradient along said first axis y during a second predetermined time interval, subsequent to said first time interval, and applying during said second time interval:
 - (1) a magnetic field gradient directed along a second axis x of said imaging sample, said second axis x being orthogonal to said first axis y, for dephasing said excited nuclear spins, and
 - (2) a magnetic field gradient directed along a third axis z of said imaging sample, said third axis z being orthogonal to said first axis y and second axis x, for phase encoding nuclear spin spatial

information along said third axis z , said phase encoding magnetic field gradient having a predetermined amplitude selected from n_z different amplitudes, wherein n_z is equal to the number of pixels in the selected tomographic section image along said third axis z ;

- applying, during a third predetermined time interval, subsequent to said second time interval, a rephasing magnetic field gradient along said second axis x , so as to rephase said nuclear spins dephased during said second time interval to produce a spin echo signal, the Fourier transform of which is a projection of nuclear spin spatial distribution information from said selected plane onto said second axis x ;
- sampling said spin echo signal n_x times in the presence of said rephasing magnetic field gradient, wherein n_x is equal to the number of pixels in the selected tomographic section image along said second axis x ;
- repeating the preceding steps for n_z different amplitudes of said magnetic field gradient along the third axis z ;
- whereby the complete planar image is reconstructed by two-dimensional Fourier transformation of the signals.

2.2 The method of Claim 1 is distinguished therefrom by the fact that it is a three-dimensional imaging method, in which the selective excitation is used for exciting the nuclear spins within a thick planar slab instead of a plane as is the case in D2, and a plurality of tomographic section images of said thick planar slab is then selected by phase encoding nuclear spin spatial distribution along the same direction chosen for the selective excitation.

2.3 None of the other cited documents discloses an extension of a two-dimensional spin-warp technique towards three-dimensional imaging comprising selective excitation and phase encoding in the same direction.

2.4 Therefore, the subject-matter of Claim 1 is new (Article 54 EPC).

3. Inventive step

3.1 Document D2, which represents the closest prior art, describes a two-dimensional spin-warp method for producing images from spin echoes of a sample in the presence of a static magnetic field and switched magnetic field gradients (cf. point 2.1 above).

Starting from this prior art, the object underlying the patent is to be seen in providing a three-dimensional NMR imaging method in which the dynamic range can controlled and the data collecting and reconstruction times are shortened (cf. column 2, lines 51 to 65 of the patent specification).

Since the drawbacks of known three-dimensional imaging methods corresponding to these objects are well known (cf. column 2, lines 20 to 50 of the patent specification), finding the problem of avoiding these drawbacks cannot, per se, be considered inventive.

3.2 The features which Claim 1 of the patent in suit proposes for solving this problem are indicated in point 2.2 above. The fact that the problem is actually solved by these features is not contested by the Appellant.

On page 1, lines 9 to 14, document D2 mentions as prior art another document (US-A-4 070 611, corresponding to document D1), and the Appellant claims that it was thus obvious to combine the teachings of this document D1 with the teachings of D2. According to D1, a series of free induction decays is obtained following nonselective excitations of the sample, magnetic field gradients in two (or three) orthogonal directions being switched on and off for specific lengths of time to yield two (or three) dimensional images; in the 3D version, two gradients are considered as being phase encoding, while the third one is used for reading out the signal (see e.g. Fig. 2 of D1), these gradients insofar corresponding to the gradients applied according to Claim 1.

However, D2 cannot be said to hint at adding the features of D1 to those of D2 if three-dimensional imaging is desired. On the contrary, in D2 the document D1 is mentioned in the sense of prior art which had serious disadvantages (high sensitivity to inhomogeneities of the static magnetic field), and the selection of a thin slab perpendicular to the y axis by means of selective excitation helps to avoid these disadvantages. There was no reason for the skilled person to go back to phase encoding in the y direction which had been overcome by the developments of D2.

Moreover, if the person skilled in the art wished to extend the method of D2 to 3D imaging, it was not at all obvious -even having regard to document D1 - in which direction he had to go. He could, for instance, envisage replacing the selective excitation of D2 by phase encoding along the third axis, thus arriving at a somewhat modified version of the method of D1 (the gradient pulse length variations and successive application of the gradients along the different axes according to D1 being replaced by

simultaneous application of gradient pulses of varying amplitudes), but not at the solution according to the patent in suit. Another obvious way of extending the teachings of D2 could have been to try to achieve an extension to three-dimensional imaging by collecting the imaging information for a series of different planes $y=y_0$, each of which is selected by a suitably tailored selective $\pi/2$ rf pulse, which alteration of the selected plane of excitation is expressly mentioned in D2 (page 5, lines 7 to 9).

Thus, by document D2, the skilled man is rather led away from the solution proposed by the patent in suit, which consists in using selective excitation as already known, however using it with an adjusted spatial range so as to define not a thin but a thick slab of the object, and additionally using a phase encoding gradient along the same axis. In the view of the Board, it was not obvious to arrive at this particular combination of features, since at first sight it seems to imply the superfluous double effort of performing the same thing twice, i.e. localisation along the same axis; the idea of performing by one of the two localisation techniques just a broad preselection of the region to be imaged is neither explicitly nor implicitly mentioned in any of the cited documents.

Thus, none of the other documents cited in addition to D1 and D2 could assist the skilled person in finding the solution claimed in the patent in suit since none of these documents mentions selective excitation and phase encoding applied along the same axis.

- 3.3 If not document D2, but D1 (three-dimensional imaging) were taken as the starting point for the considerations regarding inventive step, the results would essentially be the same.

When trying to shorten the data collecting and reconstruction times, the person skilled in the art would not be led to apply selective excitation along one axis according to D2 in addition to the phase encoding along two axes since selecting a thin slab by selective excitation would seem senseless in view of the fact that phase encoding already provides space localisation along the same axis.

3.4 With regard to the preceding, the Board concludes that the subject-matter of Claim 1 involves an inventive step (Article 56 EPC).

3.5 Claims 11 and 26 contain all the features of Claim 1 and thus have the character of dependent claims actually defining special embodiments of the subject-matter of Claim 1. These claims as well as Claims 2 to 12, 12 to 25 and 27 to 30 are allowable by virtue of their dependence on the allowable Claim 1.

Therefore, the grounds for opposition do not prejudice the maintenance of the patent unamended (Article 102(2) EPC).

Order

For these reasons, it is decided that:

The appeal is dismissed.

The Registrar:

The Chairman:

P. Martorana

W. Hofmann