

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
4 December 2003 (04.12.2003)

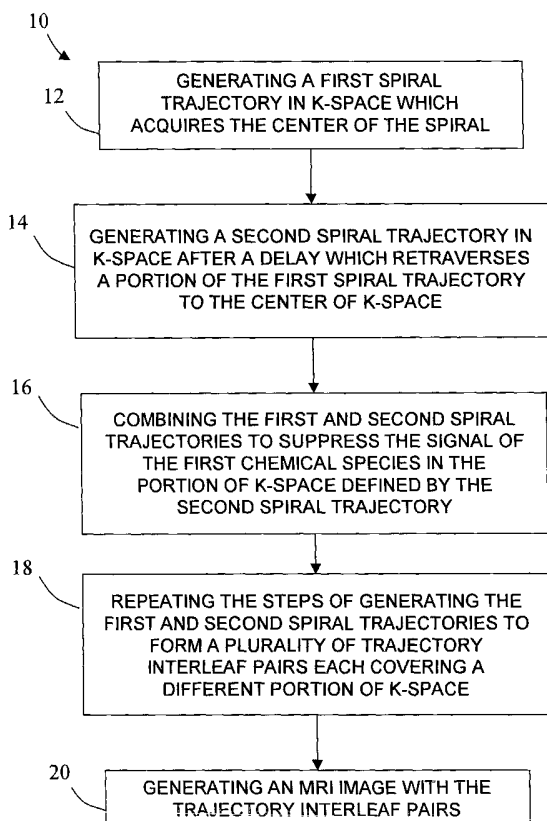
PCT

(10) International Publication Number
WO 03/100378 A2

- (51) International Patent Classification⁷: G01N (US). MORIGUCHI, Hisamoto [JP/US]; 11456 Mayfield Road #1257, Cleveland, OH 44106 (US). LEWIN, Jonathan, S. [US/US]; 24604 Letchworth Road, Beachwood, OH 44122 (US).
- (21) International Application Number: PCT/US03/10145
- (22) International Filing Date: 1 April 2003 (01.04.2003)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data: 60/381,487 17 May 2002 (17.05.2002) US
- (71) Applicant (for all designated States except US): CASE WESTERN RESERVE UNIVERSITY [US/US]; 10900 Euclid Avenue, Cleveland, OH 44106 (US).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): DUERK, Jeffrey, L. [US/US]; 519 Rockwood Court, Avon Lake, OH 44012
- (74) Agent: MINNICH, Richard, J.; Fay, Sharpe, Fagan, Minnich & McKee, LLP, 1100 Superior Avenue, 7th Floor, Cleveland, OH 44114 (US).
- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) Title: CHEMICAL SPECIES SUPPRESSION USING RE-TRAVERSAL AROUND THE K-SPACE CENTER IN INTERLEAVED REVERSED SPIRAL IMAGING



(57) Abstract: A method of suppressing a first chemical species in a subject in MR imaging includes generating a first spiral trajectory in k-space which acquires the center of the spiral, and generating a second spiral trajectory in k-space retraversing a portion of the first spiral trajectory to the center after a delay, wherein the delay is the time required for the first chemical species to rotate out of phase with a second chemical species in the subject. The method further includes combining the first and second spiral trajectories to suppress the signal of the first chemical species in the portion of k-space defined by second spiral trajectory, and repeating the steps of generating the first and second spiral trajectories to form a plurality of trajectory interleaf pairs each covering a different portion of k-space. An MR image is generated using the trajectory interleaf pairs in which the first chemical species is suppressed relative to the second chemical species.

WO 03/100378 A2



European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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.

Published:

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

CHEMICAL SPECIES SUPPRESSION USING RE-TRAVERSAL AROUND THE K-SPACE CENTER IN INTERLEAVED REVERSED SPIRAL IMAGING

BACKGROUND OF THE INVENTION

The present invention relates to a method of differentiating a chemical species in Magnetic Resonance Imaging (MRI), and more particularly to a method of suppressing a chemical species while reducing acquisition times in MRI.

A number of suppression techniques have been implemented to differentiate chemical species in MRI imaging. For example fat suppression techniques are used in MRI to differentiate fat from water in an imaged object.

Techniques such as Dixon methods achieve suppression by using additional out-of-phase k-space acquisitions. However acquiring the additional k-space data can create an undesirable increase in acquisition times. Techniques such as binomial, STIR, CHESS techniques use specialized Radio Frequency RF excitation schema to selectively excite water protons or saturate fat protons. Unfortunately, using specialized RF excitation pulses also requires additional acquisition time. Similarly, spatially spectrally selective excitation RF pulses used for suppression in both forward and reversed spiral imaging are relatively long duration pulses which also cause undesirable increases in scan time.

Longer acquisition times limit the use of these techniques for fast or real-time MR applications such as cardiac imaging. Therefore, it is desirable to provide an MR pulse sequence that enables suppression of a chemical species using relatively short acquisition times.

SUMMARY OF THE INVENTION

According to the present invention, a new and improved method of generating an MRI image by selectively suppressing one of two chemically shifted species is provided.

In accordance with a first aspect of the invention, the method includes generating a first spiral trajectory in k-space which acquires the center of the spiral, generating a second spiral trajectory in k-space retraversing a portion of the first spiral trajectory to the center after a delay, wherein the delay is the time
5 required for the first chemical species to rotate out of phase with a second chemical species in the subject. The invention further includes combining the first and second spiral trajectories to suppress the signal of the first chemical species in the portion of k-space defined by the second spiral trajectory, and repeating the steps of generating the first and second spiral trajectories to form
10 a plurality of trajectory interleaf pairs each covering a different portion of k-space.

In accordance with a second aspect of the invention, the invention includes generating an image using the trajectory interleaf pairs in which the first chemical species is suppressed relative to the second chemical species.

15 Other features, benefits and advantages of this invention will become apparent to those skilled in the art from the following detailed description of the preferred embodiments, when read in light of the accompanying drawings.

20 BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take form in certain components and structures, preferred embodiments which will be illustrated in the accompanying drawings wherein:

Fig. 1 illustrates steps of the invention;

25 Fig. 2 is a diagram illustrating the second spiral trajectory re-traversing the first spiral trajectory in k-space in accordance with the invention; and

Fig. 3 is a diagram illustrating the use of several trajectory interleaf pairs.

DETAILED DESCRIPTION OF THE INVENTION

30 Referring now to Fig. 1 a method of suppressing a first chemical species in MR imaging of a subject having first and second chemical species is shown generally at 10. In the example described herein, the first chemical species is

fat and the second chemical species is water. Although, alternatively, the first chemical species can be water and the second chemical species can be fat, or the first and second chemical species can be any other suitable chemical species exhibiting a relative difference in precession frequencies during MRI acquisitions.

The method includes generating a first spiral trajectory in k-space which acquires the center of the spiral at 12. The first spiral trajectory, shown at 22 in Fig. 2, can be generated in any suitable known manner. The first spiral trajectory 22 is shown to acquire low spatial frequencies of k-space at the center of the spiral 24. The center of the spiral 24 is located at the center, also referred to the origin, of k-space shown at 26.

The method further includes at 14 in Fig. 1, generating a second spiral trajectory in k-space after a delay which retraverses a portion of the first spiral trajectory 22 to the center of k-space 26. The delay is the time required for the first chemical species to rotate out of phase with a second chemical species present in the subject. The delay is preferably long enough for the first chemical species to rotate 180 degrees out of phase relative to the second chemical species. In the fat suppression example shown herein, a delay 2.2msec was used.

The second spiral trajectory, shown at 28 in Fig. 2, can also be generated in any suitable known manner. The first and second trajectories 22, 28 were generated using gradient waveforms with $TR/TE(\text{first})/TE(\text{second})=17.0/8.5/10.7\text{msec}$ and a 10° tip angle on a Siemens 1.5 T Magnetom Sonata (Siemens, Erlangen Germany), although any other suitable parameters can be used.

The first and second spiral trajectories 22 and 28 are preferably a reverse spiral trajectories, although alternatively the first and second spiral trajectories can both be forward spiral trajectories. The second spiral trajectory 28 is sized smaller than the first spiral trajectory 22 so it re-traverses only a portion of the first spiral trajectory, the re-traversed portion shown at 29. For example, in the example described herein, the radius, shown at r, of the second spiral trajectory 28 is approximately 30% of k_{max} of the first spiral trajectory, although the second

spiral trajectory can have any other suitable radius which is smaller than the radius of the first spiral trajectory.

The method further includes at 16 in Fig. 1, combining the first and second spiral trajectories to suppress the signal of the first chemical species in the portion of k-space defined by second spiral trajectory 28. The reversed spiral trajectories 22, 28 incorporate first moment gradient nulling at the start of the spiral and re-traversal of the center of k-space 2.2 msec after the center was initially acquired. The re-traversal goes back to a point of the original trajectory 30 and follows the same trajectory as the first spiral 22 back to the origin 26. The time difference, or delay, between the first and second traversals is the time for the first chemical species (in this example fat having a 3.5ppm chemical shift) to rotate out of phase with water by 180 degrees. Therefore, the fat signal of the first and the second traversals cancel each other in the lower frequency region of k-space when combined in step 16.

The method further includes at 18 in Fig. 1, repeating the steps of generating the first spiral trajectory 14 and generating the second spiral trajectory 16 to form a plurality of trajectory interleaf pairs each covering a different portion of k-space. The gradient waveforms of the interleaf pairs were incorporated into a 12-interleave reversed spiral sequence to achieve a sufficiently high sampling density of k-space. Since each spiral interleaf reaches the k-space origin twice, two bipolar gradients were incorporated for flow compensation. Though 12-interleaf trajectory pairs were used in the example described herein, any suitable number of interleaf trajectory pairs can be used to sample a sufficient amount of k-space. For example, Fig. 3 shows the use of 3 interleaf trajectory pairs, 22a and 28a, 22b and 28b, and 22c and 28c, each covering a different portion of k-space.

The method further includes at 20 in Fig. 1, generating an MR image using the trajectory interleaf pairs in which the first chemical species is suppressed relative to the second chemical species. The MR image can be generated in any suitable known manner using the trajectory interleaf pairs.

All the MR images were reconstructed using a modified known Block Uniform Resampling (BURS) regridding algorithm, although any other suitable

known methods of image reconstruction can be used. The slice thickness was 10mm and the Field of View (FOV) was 210mm x 210mm, although any suitable slice thickness and FOV can be used.

5 A short duration re-traversal around the center of k-space after the spiral trajectory reaches the center of k-space has been shown to be an effective fat suppression technique in reversed spiral imaging. The total scan time is only minimally affected since each spiral interleaf needs only 2.2ms of additional readout time for each spiral interleaf in a 1.5T MR system. In a 12 interleave spiral sequence, this results in a 26.4 msec increase (2.2ms x 12 interleaves) in
10 scan time for fat suppression through re-traversal, versus about 60 msec additional scan time for a 5 msec spatial spectral pulse (using a 5 msec pulse with 12 interleaves).

The invention has been described with reference to preferred
embodiments. Obviously, modifications and alterations will occur to others upon
15 reading and understanding the preceding specification. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. A method of suppressing a first chemical species in a subject using Magnetic Resonance Imaging comprising:

5 generating a first spiral trajectory in k-space which acquires the center of the spiral;

generating a second spiral trajectory in k-space retraversing a portion of the first spiral trajectory to the center after a delay, wherein the delay is the time required for the first chemical species to rotate out of phase with a second
10 chemical species in the subject;

combining the first and second spiral trajectories to suppress the signal of the first chemical species in the portion of k-space defined by second spiral trajectory; and

15 repeating the steps of generating the first and second spiral trajectories to form a plurality of trajectory interleaf pairs each pair covering a different portion of k-space.

2. The method of suppressing a first chemical species defined in claim 1 further including generating an image using the trajectory interleaf pairs
20 in which the first chemical species is suppressed relative to the second chemical species.

3. The method of suppressing a first chemical species defined in claim 1 wherein the delay is the time difference required for the first chemical
25 species to rotate 180° out of phase relative to the second chemical species.

4. The method of suppressing a first chemical species defined in claim 1 wherein the first and second spiral trajectories are reverse spiral trajectories.

30

5. The method of suppressing a first chemical species defined in claim 1 wherein the first and second spiral trajectories are forward spiral trajectories.

5 6. The method of suppressing a first chemical species defined in claim 1 wherein the repeating step forms 12 interleaf pairs.

7. The method of suppressing a first chemical species defined in claim 1 wherein the radius of the second trajectory is approximately 30% of k_{\max} .

10

8. The method of suppressing a first chemical species defined in claim 1 wherein the first trajectory includes a gradient waveform with TR/TE = 17.0/8.5 msec and a 10° tip angle and the second trajectory includes a gradient waveform with TR/TE = 17.0/10.7 msec and a 10° tip angle.

15

9. The method of suppressing a first chemical species defined in claim 1 wherein the first chemical species is fat and the second chemical species is water.

20 10. The method of suppressing a first chemical species defined in claim 1 wherein the first chemical species is water and the second chemical species is fat.

25 11. A method of suppressing fat in a subject having fat and water using Magnetic Resonance Imaging comprising:

generating a first spiral trajectory in k-space which acquires the center of the spiral;

generating a second spiral trajectory in k-space retraversing a portion of the first spiral trajectory to the center after a delay, wherein the delay is the time required for the fat to rotate out of phase with the water ;

30

combining the first and second spiral trajectories to suppress the signal of the fat in the portion of k-space defined by second spiral trajectory; and

repeating the steps of generating the first and second spiral trajectories to form a plurality of trajectory interleaf pairs each pair covering a different portion of k-space.

5 12. The method of suppressing fat defined in claim 11 further including generating an image using the trajectory interleaf pairs in which the fat is suppressed relative to the water.

10 13. The method of suppressing fat defined in claim 11 wherein the first and second spiral trajectories are reverse spiral trajectories.

14. The method of suppressing fat defined in claim 11 wherein the first and second spiral trajectories are forward spiral trajectories.

15 15. The method of suppressing fat defined in claim 11 wherein the repeating step forms 12 interleaf pairs.

16. The method of suppressing fat defined in claim 11 wherein the radius of the second trajectory is approximately 30% of k_{\max} .

20

17. The method of suppressing fat defined in claim 11 wherein the delay is the time difference required for the fat to rotate 180° out of phase relative to the water.

25 18. A method of suppressing fat in a subject having fat and water using Magnetic Resonance Imaging comprising:

generating a first spiral trajectory in k-space with a gradient waveform with TR/TE(first)= 17.0/8.5/msec and a 10° tip angle which acquires the center of the spiral;

30

generating a second spiral trajectory in k-space with a gradient waveform with TR/TE(second)= 17.0/10.7msec and a 10° tip angle retraversing a portion

of the first spiral trajectory to the center after a delay, wherein the delay is the time required for the fat to rotate 180° out of phase with the water;

combining the first and second spiral trajectories to suppress the signal of the fat in the portion of k-space defined by second spiral trajectory;

5 repeating the steps of generating the first and second spiral trajectories to form a plurality of trajectory interleaf pairs each pair covering a different portion of k-space; and

generating an image using the trajectory interleaf pairs in which the fat is suppressed relative to the water.

10

19. The method of suppressing fat defined in claim 18 wherein the first and second spiral trajectories are reverse spiral trajectories.

20. The method of suppressing fat defined in claim 18 wherein the
15 radius of the second trajectory is approximately 30% of k_{\max} .

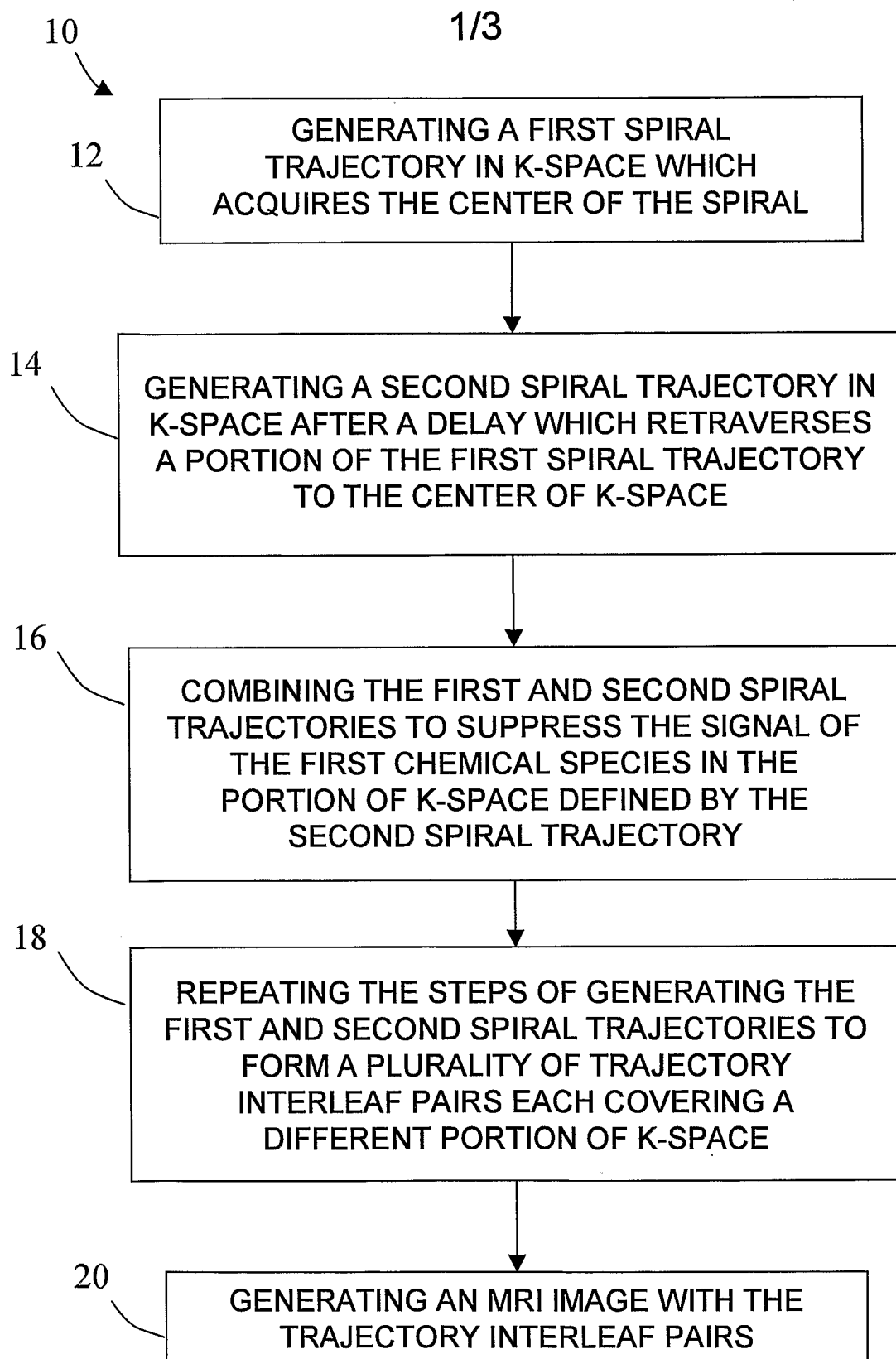


Fig. 1

2/3

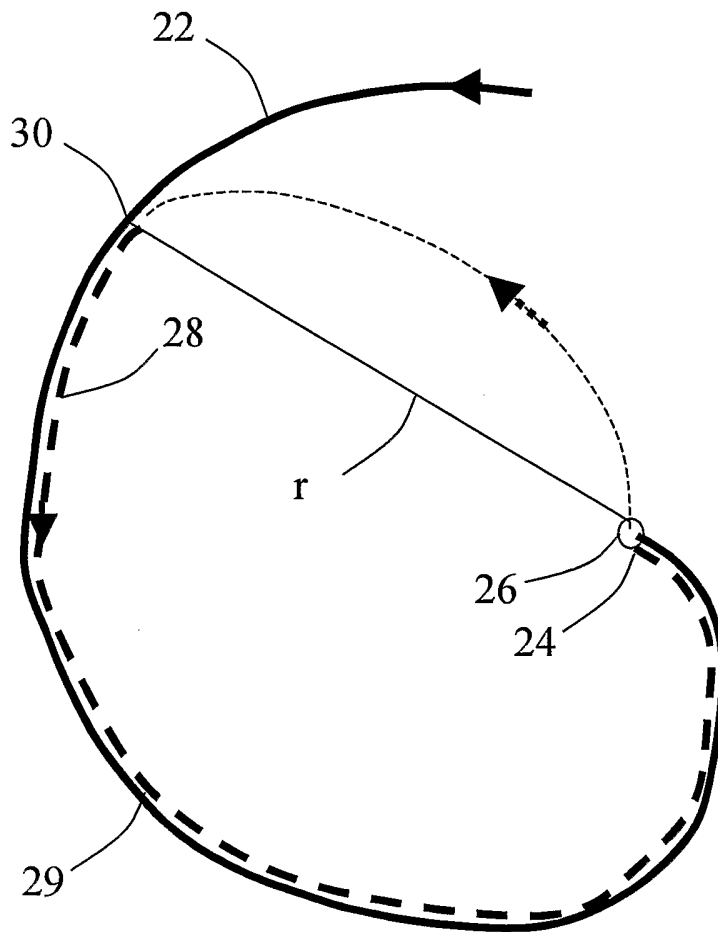


Fig. 2

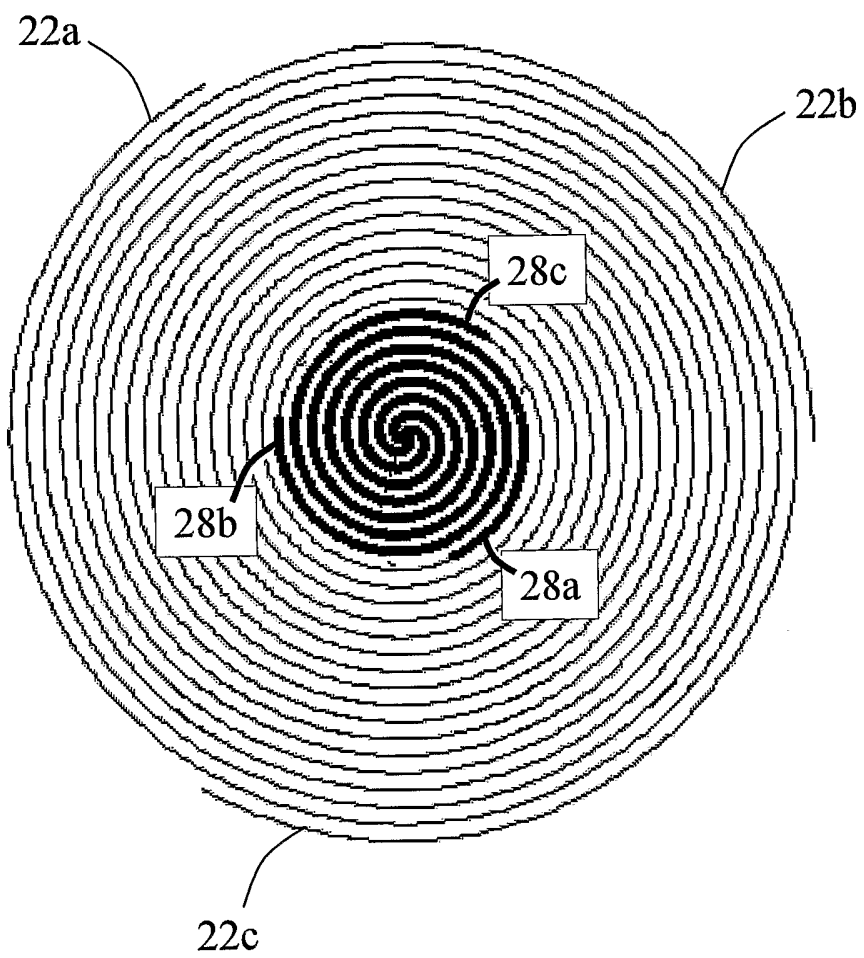


Fig. 3