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(54) Title: PASSIVE B1 FIELD SHIMMING

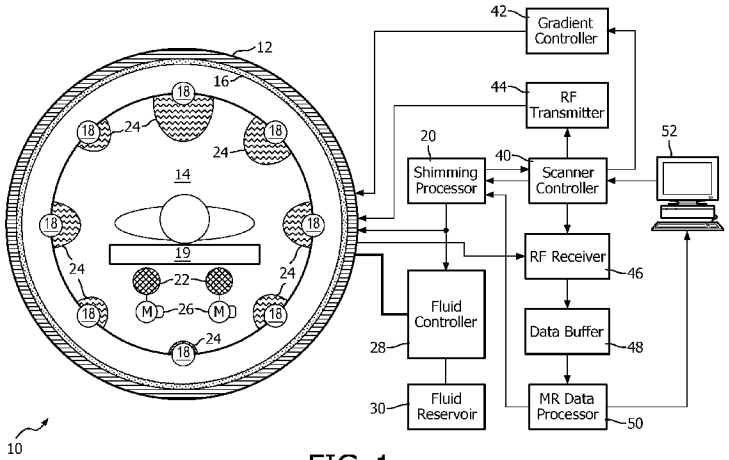


FIG. 1

(57) Abstract: Coil elements (18) generate a B_1 excitation field in an examination region (14), which B_1 excitation field is distorted by patient loading (e.g., wavelength effects). Passive shimming elements (22, 24) are disposed between the coil elements and the subject in order to improve the B_1 field uniformity. In one embodiment, passive shimming elements include one or more dielectric rods (55) disposed below the subject which generate no substantial MR proton signal and which have a permittivity of at least 100 and preferably greater than 500. In another embodiment, tubes (24) adjacent each coil element are supplied with a dielectric liquid, a thickness of the dielectric liquid between the coil element and the subject adjusting a phase of the B_1 field generated by the coil element. Active B_1 shimming may be combined with passive shimming elements (22, 24) to effect an improved RF field homogeneity result.

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PASSIVE B1 FIELD SHIMMING

DESCRIPTION

The present application relates to the magnetic resonance arts. It finds particular application in relation to radiofrequency (RF) coils and magnetic field correction generated therefrom. However, it also finds application in magnetic resonance imaging, spectroscopy and other nuclear magnetic resonance techniques.

Loading from a patient to be examined distorts the B_1 excitation field. The distortion varies with the size and shape of the subject, and the operational radio frequency. This distortion becomes particularly acute above 3 Tesla, which has an operational radio frequency for hydrogen of approximately 128 MHz. The lack of B_1 uniformity causes artifacts in the resultant images or other magnetic resonance results.

The present application provides a new and improved system and method which overcomes the above-referenced problems and others.

In accordance with one aspect, a magnetic resonance system is provided. Radio frequency coil elements are disposed adjacent an examination region to generate a B_1 excitation field in the examination region. At least one shimming device is disposed in the examination region between the RF coil elements and a subject to improve the uniformity in the generated B_1 excitation field. The passive shimming device has a prearranged position, dimension, and dielectric permittivity. It is noted that, in this context, the examination region includes the entire space within the RF coil. In some cases, such as a whole body RF coil the examination region, in this context, is larger than the usual imaging volume.

In accordance with another aspect, a method for passively shimming a B_1 excitation field is provided. At least one passive shimming device is disposed in an examination region defined inside of the coil elements of an RF coil. The passive shimming elements improve uniformity in the B_1 excitation field. The at least one passive shimming element has a prearranged position, dimension, and dielectric permittivity.

One advantage is that B_1 excitation uniformity is improved.

Another advantage is that work flow for MR imaging at high fields strengths is improved.

Another advantage is that signal-to-noise ratio is improved.

Still further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 is a diagrammatic illustration of a magnetic resonance system which includes passive shimming devices;

FIGURE 2 is another diagrammatic illustration of the magnetic resonance system and passive shimming devices;

FIGURE 3 illustrates a female body-shaped phantom in a quadrature birdcage body coil with and without dielectric passive shimming rods;

FIGURE 4 illustrates B_1 distributions with various shimming combinations using a quadrature birdcage body coil with two independent transmit/receive channels;

FIGURES 5A and 5B illustrate a symmetric placement of two shimming rods disposed below a phantom and the resultant B_1 field distribution using a quadrature birdcage body coil with two independent transmit/receive channels;

FIGURES 5C and 5D illustrate a single passive shimming rod disposed below the phantom and the corresponding B_1 distribution using a quadrature birdcage body coil with two independent transmit/receive channels;

FIGURE 6 illustrates a symmetric placement of passive shimming rods below a slim body-shaped phantom and resultant B_1 field distributions with quadrature driven RF coils and no dielectric rods, with B_1 shimming without dielectric rods, and shimming with the dielectric rods;

FIGURE 7 illustrates an RF head coil with a human head model in which the passive shimming element includes a water balloon and the resultant B_1 distribution with and without the water balloon; and

FIGURE 8 illustrates a method of using the passive shimming elements.

With reference to FIGURES 1 and 2, a magnetic resonance (MR) imaging system **10** includes a main magnet **12** which generates a spatial and temporally uniform B_0 field of at least 3 Tesla and above through an examination region **14**. The main magnet can be an annular or bore-type magnet, or the like. Gradient magnetic field coils **16** disposed adjacent the main magnet serve to generate magnetic field gradients along selected axes relative to the B_0 magnetic field for spatially encoding magnetic resonance signals, for producing magnetization-spoiling field gradients, or the like. The magnetic field gradient coil **16** may include coil segments configured to produce magnetic field gradients in three orthogonal directions, typically longitudinal or z, transverse or x, and vertical or y directions.

A radio-frequency (RF) coil assembly, such as a whole-body radio frequency coil, is disposed adjacent the examination region. The RF coil assembly may include a plurality of individual RF coil elements **18**, or may be a birdcage-type coil with the multiple elements **18** interconnected by end ring RF coil structures. In the illustrated embodiment, eight coil elements **18** are shown. However, more or less coil elements **18** are also contemplated. The RF coil assembly generates radio frequency pulses for exciting magnetic resonance in aligned dipoles of the subject. In some embodiments, the radio frequency coil assembly **18** also serves to detect magnetic resonance signals emanating from the imaging region. In other embodiments, local or surface RF coils (not shown) are provided in addition to or instead of the whole-body RF coil for more sensitive, localized spatial encoding, excitation, and reception of magnetic resonance signals. The individual RF coils **18** together can act a single coil, as a plurality of independent coil elements, as an array such as in a parallel transmit system, or a combination. For example, where the RF coil **18** is configured as a birdcage-type coil the two modes may be driven independently for purposes of RF shimming.

To improve homogeneity of the B_1 field, or excitation field, in the examination region **14**, a uniformity distribution $|B_1^+|$of the transmit coils **18** is determined by a shimming processor **20**, e.g. by a short measurement prior to the actual imaging sequence to compensate for dielectric resonances occurring in patient tissue at high frequencies, i.e. Larmor frequency at static fields strengths, particularly at 3 Tesla or

greater. The imaging system **10** includes one or more passive shimming devices **22**, **24** disposed in the examination region **14** to improve the homogeneity of the excitation field.

In one embodiment, the passive shimming devices are dielectric rods **22** composed of a solid dielectric material having a dielectric permittivity (ε_r) of at least 100. Several dielectric rods **22** with varying length, shape, and dielectric permittivity are available to optimize the homogeneity of the B_1 excitation field. Shapes include cylindrical, elliptical, rectangular, or the like. The shimming processor **20** determines the number, length, and position of the dielectric rods to be disposed in the examination region based on the determined uniformity distribution which optimizes homogeneity of the B_1 excitation field. In order not to disrupt the workflow of an imaging procedure, the rods **22** are disposed on a lower side of the subject as stand-alone structures in the examination region **14** or as part of the patient support **19**. The rods can be manually positioned in the examination region **14** by a clinician or automatically by an actuator **26**, such as non-ferromagnetic motor or the like. The actuator receives the determined position of the rods **22** from the shimming processor **20** and adjusts the x, y, and z position and rotation accordingly. The actuator **26** can remove one or more of the rods **22** or introduce additional rods into the examination region **14** without user intervention.

In another embodiment, the shape, size, placement, and dielectric permittivity of the rods are determined for a nominal patient and the rods are fixedly mounted. In another embodiment, the shape, size, placement, and dielectric permittivity are calculated for a plurality of groups or classes of patients, such as large or obese, normal or average, and petite.

In another embodiment, the passive shimming devices include tubes **24** of dielectric fluid, each being disposed adjacent to a corresponding coil element **18** in-between the examination region **14** and the individual coil **18**. Examples of dielectric fluids include heavily doped water, heavy water, or other non-proton MR signal generating fluid. The volume of dielectric fluid in each tube **24** is adjusted by a fluid controller **28** according to the uniformity distribution to optimize the homogeneity of the B_1 excitation field. A fluid reservoir **30** supplies the dielectric fluid to the fluid controller **28** which supplies the fluid to each tube **24** via supply lines **25** routed through a gantry housing of the imaging system **10**. The reservoir **30** may include a plurality of sub-reservoirs, each of which includes dielectric fluid with a unique dielectric permittivity. In this arrangement, the fluid

controller **28** can supply dielectric fluid from one or more of the sub-reservoirs to each tube **24**. Therefore, the dielectric permittivity of each tube can be tuned by adjusting the dielectric permittivity of the fluid and the volume of the fluid.

The tubes **24** can have the same or different lengths, in the axial direction, of the corresponding coil element **18** adjacent the tube. In one embodiment, the tubes **24** include a serpentine structure to ensure a uniform cross-section along the length of the tube or a uniform volume in the axial direction. In another embodiment, each tube is segmented in the axial direction. The fluid controller **28** can adjust the volume of each segment to account for non uniform dielectric load by the patient in the axial direction. For example, the head, torso, and legs exhibit varying dielectric loading because of the size, geometry, internal structure, and density of the corresponding anatomical region. In a further embodiment, each segment includes a serpentine structure to ensure that each segment has a uniform cross-section or volume in the axial direction. In another embodiment, the tubes **24** are or include expandable bladders or other structures to control the distribution of liquid between each coil element **18** and the imaging region **14**. For one example, a uniform thickness of liquid can be formed around the side of the coil element towards the imaging region. For another example, a parabolic distribution can be provided.

In another embodiment, the imaging system **10** includes both the dielectric rods **22** and the tubes **24** of dielectric fluid to shim the B_1 excitation field for optimal homogeneity. After analysis of the uniformity distribution, the shimming processor **20** determines the optimal size, geometry, dielectric permittivity, and position of each dielectric rod **22** and the shimming processor **20** determines the optimal volume and dielectric permittivity of each tube **24** which affords the optimal B_1 excitation field for the imaging subject. For example, the size, geometry, dielectric permittivity, and position of the rods **22** can be fixed and the liquid in the tubes **24** can be used to fine tune the B_1 field.

Once the B_1 excitation field is optimized for the imaging subject, magnetic resonance data of the subject is acquired. The subject remains inside the examination region **14** in the same position as when the uniformity distribution was determined. A scan controller **40** controls a gradient controller **42** which causes the gradient coils **16** to apply the selected magnetic field gradient pulses across the imaging region, as may be appropriate to a selected magnetic resonance imaging or spectroscopy sequence. The scan controller **40** also controls at least one RF transmitter **44** which causes the RF coil

assembly to generate magnetic resonance excitation and manipulation of B_1 pulses. In a parallel system, the RF transmitter **44** includes a plurality of transmitters or a single transmitter with a plurality of transmit channels, each transmit channel operatively connected to at least one corresponding coil element **18** of the assembly. In the case of a birdcage-type RF coil the transmitter may have two independent channels to drive the two modes of the birdcage. The scan controller, in coordination with the shimming processor, also controls the transmitter and gradient controller to generate B_1 shimming sequences and B_1 shimmed sequences.

The scan controller also controls an RF receiver **46** which is connected to the RF coils **18**, and/or a dedicated receive coil placed inside the examination region **14**, to receive magnetic resonance signals therefrom. In a parallel system, the RF receiver **46** includes a plurality of receivers or a single receivers with a plurality of receive channels, each receive channel operatively connected to at least one corresponding coil element **18** of the assembly. The received data from the receiver **46** is temporarily stored in a data buffer **48** and processed by a magnetic resonance data processor **50**. The magnetic resonance data processor can perform various functions as are known in the art, including image reconstruction, magnetic resonance spectroscopy processing, catheter or interventional instrument localization, and the like. Reconstructed magnetic resonance images, spectroscopy readouts, interventional instrument location information, and other processed MR data are displayed on a graphical user interface **52**. The graphic user interface **52** also includes a user input device which a clinician can use for controlling the scan controller **40** to select scanning sequences and protocols, and the like.

In another embodiment, the imaging system **10** is a parallel transmit system with a plurality of RF transmitters **44**. The shimming processor **20** determines unique a phase and amplitude component for each excitation signal generated by the individual RF transmitters **44** based on the analyzed uniformity distribution. In this arrangement, the B_1 excitation field is optimized by varying the generated B_1 excitation field transmitted by the individual coil elements **18**. For example, in a two-channel parallel transmit system the imaging system **10** includes two RF transmitters **44** where each transmitter is operatively connected to one or more feed points of the coil elements **18** or connected to drive the two modes of a birdcage-type RF coil. The shimming processor determines changes in the phase and amplitude of B_1 excitation signal for each channel such that the composite B_1

excitation field resulting from the two channels is optimized for homogeneity. The shimming processor controls the amount of fluid in each tube **24** to adjust the relative phase of RF field produced by coil segments associated with the same transmitter.

In another embodiment, the imaging system **10** includes the dielectric rods **22**, the tubes **24** of dielectric fluid, and the parallel transmit system with multiple RF transmitters **44** to shim the B_1 excitation field for optimal homogeneity. After analysis of the uniformity distribution, the shimming processor **20** determines the optimal size, geometry, dielectric permittivity, and position of each dielectric rod **22**; the optimal volume distribution, and dielectric permittivity of dielectric fluid for each tube **24**; and unique phase and amplitude components for each excitation signal generated by each of the RF transmitters **44**. As a result, the homogeneity of the overall B_1 field is substantially improved at higher field strengths for the imaging subject.

With reference to FIGURES 3 and 4, the improvement of homogeneity of the B_1 excitation field is illustrated in a Finite-difference time-domain (FDTD) model for a 3 Tesla imaging system **10**. The RF assembly in this embodiment is a birdcage-type quadrature body coil (QBC) loaded with a female body-shaped phantom. The QBC is driven with two independent transmit/receive (T/R) channels. With reference to FIGURE 4, as seen, $|B_1^+|$ over the center transverse slice of the phantom is relatively non-uniform. Considering $|B_1^+|$-shimming over the torso region only (excluding both arms and breasts), (a) shows that, in a conventional quadrature feed case, the $|B_1^+|$ standard deviation (divided by mean field, no units) in the torso area is 0.33. When using two channel transmit, $|B_1^+|$ standard deviation can be reduced to 0.23, a 30% improvement, as shown in (b). As seen in (b), the shimmed $|B_1^+|$ is still not quite uniform with higher $|B_1^+|$ over upper-right area and lower $|B_1^+|$ over bottom-left area. The ratio of maximum $|B_1^+|$ over minimum $|B_1^+|$ is 3.6 when comparing to 7 for convention quadrature feed (a).

Continuing with reference to FIGURE 4, to further improve $|B_1^+|$ uniformity, two dielectric rods are inserted in the bottom left area and right area of the phantom adjacent to the phantom (as depicted in FIGURE 3). The diameter of the rods is 4cm with length of 65cm and a dielectric constant $\varepsilon_r = 1000$. The rods are separated 31cm apart. As seen in (c), even though the cross-section of two rods is relatively small compared with that of the body phantom, $|B_1^+|$ field distribution is re-distributed over the $|B_1^+|$ shimming area. When permittivity ε_r is reduced to 100, as shown in (d), a better

shimmed $|B_1^+|$ is achieved with deviation of 0.19, which is 42% better than 0.33 result for the un-shimmed quadrature feed case; the result is also better than the 0.23 deviation of (b) when RF shimming only is used. The ratio of maximum $|B_1^+|$ over minimum $|B_1^+|$ is 3.3, better than the optimal 2-channel shimming case result of 3.6 in (b) without the rods.

With reference to FIGURES 5A and 5B, in another scenario, two same-sized rods are placed away from the phantom which would model the rods **22** being placed inside the patient table **19**. The distance from the two rods to the isocenter of the QBC is 15.5cm, the $\varepsilon_r = 1000$ for both of the rods **22** in this case, and the two rods **22** are positioned 31cm apart. As seen from the shimmed $|B_1^+|$ in FIGURE 5B, over the defined shimming area $|B_1^+|$ the standard deviation is reduced to 0.16, 52% less than the un-shimmed quadrature driven case result of 0.33 in (a) of FIGURE 4 and 30% less than the shimmed quadrature driven case result of 0.23 in (b) of FIGURE 4 without the dielectric rods. The ratio of maximum $|B_1^+|$ over minimum $|B_1^+|$ is 2.2 comparing with 3.6 of shimmed case without the use of dielectric rods.

With reference to FIGURE 5C and 5D, when local receive coils are used, one dielectric rod can be used to improve only the transmit $|B_1^+|$-field. As shown in FIGURE 5C and 5D, the shimmed $|B_1^+|$ case with dielectric rod ($\varepsilon_r = 1000$) positioned to the left of the phantom, the $|B_1^+|$ distribution is almost identical to that of two rods case in FIGURE 5A and 5B. From the model, the left dielectric rod (FIGURE 5C) has a greater $|B_1^+|$ shimming influence than the right dielectric rod during RF field transmission. On the other hand, the right dielectric rod has much more effect on the $|B_1^-|$ shimming during reception of the MR signal.

In above calculations using the FDTD model, we used a "body-shaped" female phantom body model with the aspect ratio of 0.60 (anterior-posterior width over left-right width in the torso center transverse slice). The same calculations are also repeated for a "body-shaped" male phantom body model with a slimmer aspect ratio of 0.46 (modified from the female model by removing the breast and reducing the aspect ratio). FIGURE 6 shows the $|B_1^+|$-field over the center transverse slice excluding arms (shimming area). As seen, with the addition of dielectric rods ($\varepsilon_r = 1000$), $|B_1^+|$ uniformity is also improved further from the shimming case without the dielectric rods.

To further optimize $|B_1^+|$ uniformity using one or more dielectric rod(s) **22**, the rod diameter, size, the optimal permittivity ε_r, and positions can be determined through

the FDTD modeling or other numerical calculations with the shimming processor **20**. The dielectric rods can either be mobile, e.g., used inside the patient accessible area of the bore, or be placed in permanent positions under the patient table (i.e., non-patient accessible area of the bore). The dielectric rods can be made of materials without proton MR signals (heavily doped water to mitigate proton signal, or ceramics without substantial electrical conductivity). They are relatively small and can be inserted into the QBC space.

With reference to FIGURE 7, a 7 Tesla head T/R coil model was driven in quadrature using a single transmit channel with a quadrature T/R switch. One rectangular water balloon with dimension of 4cm x 2.5cm x 16.5cm is placed between two coil rungs and a human head model. Calculated $|B_1^+|$-field in the center transverse slice is also shown ($|B_1^+|$ is normalized to the field at the center). As shown, the $|B_1^+|$ standard deviation (divided by mean value, no units) for the conventional quadrature driven case is 0.232. With the addition of one water balloon, it reduced to 0.225, a 3% reduction of $|B_1^+|$ field non-uniformity. In other cases, when more than one water balloons are used, the sizes and positions of these water balloons can be optimized. The conductivity (salt level) can also be optimized for individual water balloons, we expect even more improvement of $|B_1^+|$ uniformity.

With reference to FIGURE 8, a method for shimming a B_1 excitation field is presented. After a subject is positioned in the examination region, a B_1 field is generated and its uniformity is analyzed **S100** by the shimming processor **20**. Based on the analyzed uniformity distribution $|B_1^+|$, the shimming processor **20** determines the position, dimensions, and dielectric permittivity ε_r **S102** of the dielectric rods **22** to be disposed in the examination region **14** and/or the volume and ε_r **S104** of the dielectric fluid supplied to each tube **24;** and the excitation signal **S106** for each independent transmit channel T_x. The actuator **26** selects and positions the dielectric rods **22** accordingly **S108**. The fluid controller **28** adjusts the volume and ε_r of the dielectric fluid accordingly **S110**. Optionally, steps **S100-S110** can be iteratively repeated to optimize the B_1 uniformity. Once the passive shimming devices **22**, **24** are tuned according to the analyzed uniform distribution, the RF transmitter **44** causes the coils elements **18** associated with each transmit channel to apply a shimmed B_1 excitation field **S112** to the examination region **14** according to the excitation signals determined in step **S106**. The induced MR signals are received **S114** by the RF receiver **48** via the coil elements **18** or a dedicated receive coil in examination

region **14** and reconstructed **S116** into an image representation of the subject by the data processor **50**. The image representation is displayed on the graphical user interface **52**.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

Having thus described the preferred embodiments, the invention is now claimed to be:

1. A magnetic resonance system (10), comprising:

radiofrequency (RF) coil elements (18) adjacent to an examination region (14) which generates a B_1 excitation field in the examination region according to a generated excitation signal; and

at least one passive shimming device (22,24) disposed in the examination region (14) between the at least one RF coil (18) and a subject which improve uniformity in the generated B_1 excitation field, the at least one passive shimming device (22,24) having a prearranged position, dimensions, and dielectric permittivity.

2. The magnetic resonance system (10) according to claim 1, further including:

a shimming processor (20) which analyzes a B_1 distribution of the generated excitation field and determines at least one of a position, dimensions, and dielectric permittivity for the at least one passive shimming device (22, 24) which improves a uniformity of the B_1 distribution to optimize a B_1 homogeneity of the excitation field.

3. The magnetic resonance system (10) according to either one of claims 1 and 2, wherein the at least one passive shimming device is a rod (22) composed of a solid dielectric material.

4. The magnetic resonance system (10) according to claim 3, further including:

an actuator (26) which positions the dielectric rod (22) in the examination region (14) according to an uniformity distribution of the examination region.

5. The magnetic resonance system (10) according to either one of claims 3 and 4, wherein the at least one dielectric rod (22) is disposed on a lower side of the subject.

6. The magnetic resonance system (10) according to any one of claims 3-5, wherein the dielectric permittivity of the dielectric rod (22) is at least 100, preferably greater than 500.

7. The magnetic resonance system (10) according to any one of claims 3-7, further including:

a tube or reservoir (24) with a variable volume of dielectric fluid disposed adjacent to each of the coil elements (18).

8. The magnetic resonance system (10) according to any one of claims 1-6, wherein the at least one passive shimming device includes one or more tubes (24) with a volume of dielectric fluid disposed adjacent to the RF coil elements.

9. The magnetic resonance system (10) according to either one of claims 7 and 8, further including:

a reservoir (30) which supplies the dielectric fluid to each of the tubes (22); and

a fluid controller (28) which controls at least one of the volume of dielectric fluid in each tube (22) and the dielectric permittivity of the dielectric fluid supplied to each tube (22) according to the analyzed uniformity distribution.

10. The magnetic resonance system (10) according to any one of claims 1-9, further including:

two or more RF transmitters (44), each which generates an excitation signal for transmission via the RF coil elements (18) to generate a passively shimmed excitation field.

11. The magnetic resonance system (10) according to any one of claims 1-10, wherein the RF coil elements (18) form a birdcage-type RF coil (18) and the two or more RF transmitters (44) each generate an excitation signal for transmission via the birdcage-type RF coil (18) to generate a passively and actively shimmed excitation field.

12. The magnetic resonance system (10) according to either one of claims 10 and 11, wherein the shimming processor (20) controls each of the RF transmitters (44) to generate a unique excitation signal according to the analyzed uniformity distribution to improve homogeneity of the passively shimmed excitation field.

13. The magnetic resonance system (10) according to any one of claims 1-12, further including:

a main magnet (12) which generates a static magnetic field of at least 3 Tesla in the examination region (14); and

at least one RF receiver (46) which receive induced MR signals from examination region resulting from the excitation signal.

14. A method for passively shimming a B_1 excitation field, comprising:

disposing at least one passive shimming device (22, 24) in an examination region (14) defined inside of coil elements (18) of an RF coil to improve uniformity in the B_1 excitation field generated by the RF coil, the at least one passive shimming device (22, 24) having a prearranged position and dielectric permittivity.

15. The method according to claim 14, further including:

analyzing a B_1 distribution of the generated excitation field; and

determining at least one of a position, dimensions, and dielectric permittivity for the at least one passive shimming device (22, 24) which improves a B1 uniformity of the generated excitation field.

16. The method according to either one of claims 14 and 15, wherein the at least one passive shimming device includes at least one rod (22) composed of a solid dielectric material without a substantial MR proton signal and with a permittivity greater than 100 and preferably greater than 500.

17. The method according to any one of claims 14-16, wherein the at least one passive shimming device includes tubes (24) each with a volume of dielectric fluid disposed adjacent to elements (18) of the at least one RF coil.

18. The method according to either one of claims 16 and 17, further including:

with a controller (26, 28), controlling at least one of the volume of dielectric fluid in each tube (24) and a position of the at least one rod.

19. The method according to claim 16, further including:

selecting one of a plurality of rods of different sizes and/or permittivity in accordance with a size of a subject to be examined; and

positioning the selected rod in the examination region.

20. A magnetic resonance system (10), comprising:

an examination region (14) for receiving a subject to be examined;

a plurality of radiofrequency (RF) coil elements (18) adjacent to the examination region (14) which generate an excitation field in the examination region according to a generated excitation signal;

two or more RF transmitters (44), each which generates an excitation signal for transmission via at least one of the plurality of RF coils (18) to generate a B_1 excitation field;

a passive shimming device including at least one of:

a rod (22) composed of a solid dielectric material without a proton signal and with a permittivity greater than 100 disposed in the examination region (14) at a prearranged position below the subject to passively shim the generated B_1 excitation field;

a plurality of tubes (24) configured to receive a variable volume of dielectric fluid disposed adjacent to the plurality of RF coil elements (18) to passively shim the generated B_1 excitation field; and

a shimming processor (20) which analyzes uniformity of the B_1 excitation field in the examination region and therefrom determines at least one of (a) at least one of a

position, dimensions, and/or dielectric permittivity of the rod (22), (b) the volume of dielectric fluid in each tube (22) and/or the dielectric permittivity of the dielectric fluid supplied to each tube (22), (c) amplitude and/or phase settings for the two or more RF transmitters (44).

5

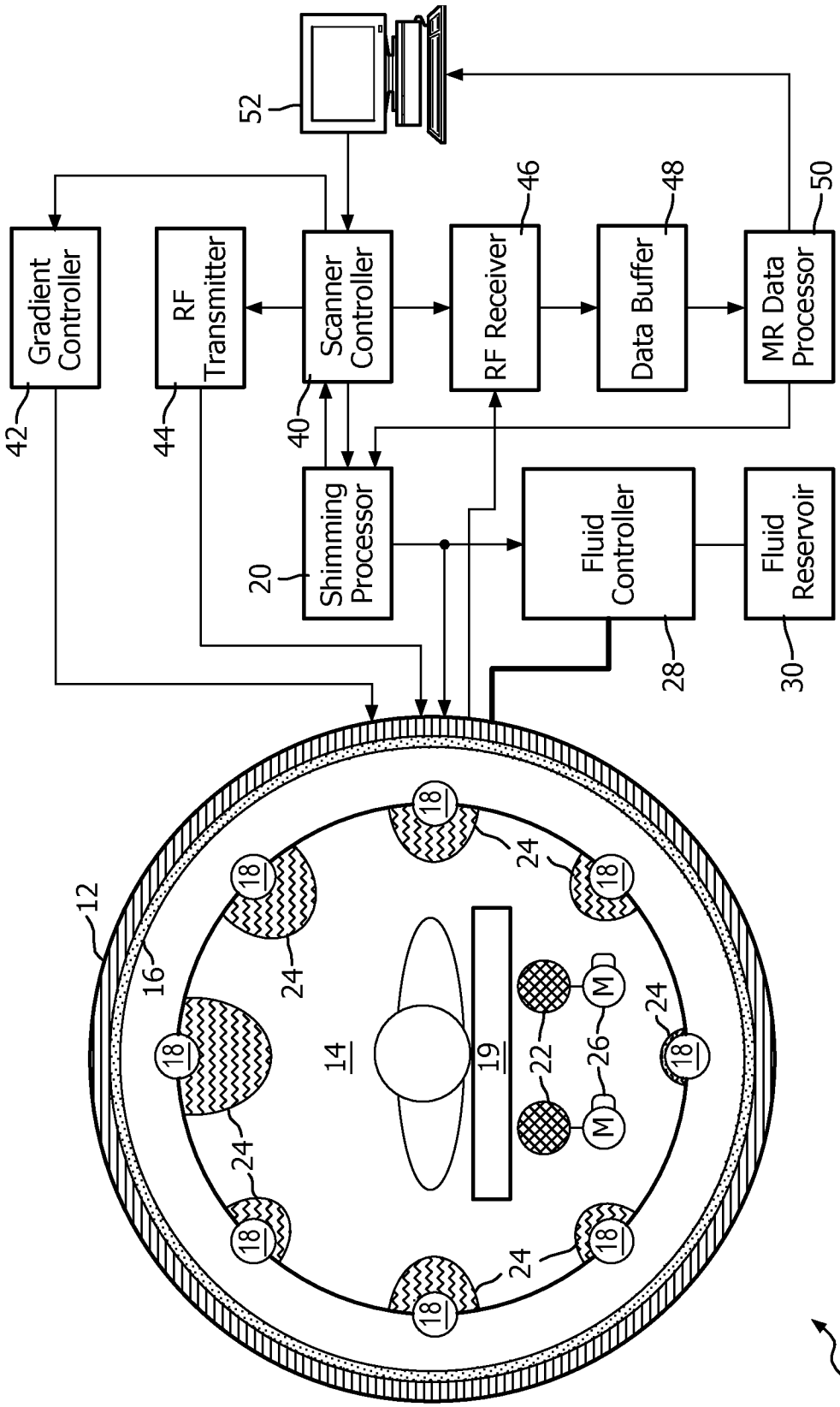

52
Gradient Controller
RF Transmitter
Scanner Controller
RF Receiver
Data Buffer
MR Data Processor
42
44
40
46
48
50
Shimming Processor
Fluid Controller
Fluid Reservoir
20
28
30
12
16
14
19
18
24
22
26
M
10

FIG. 1

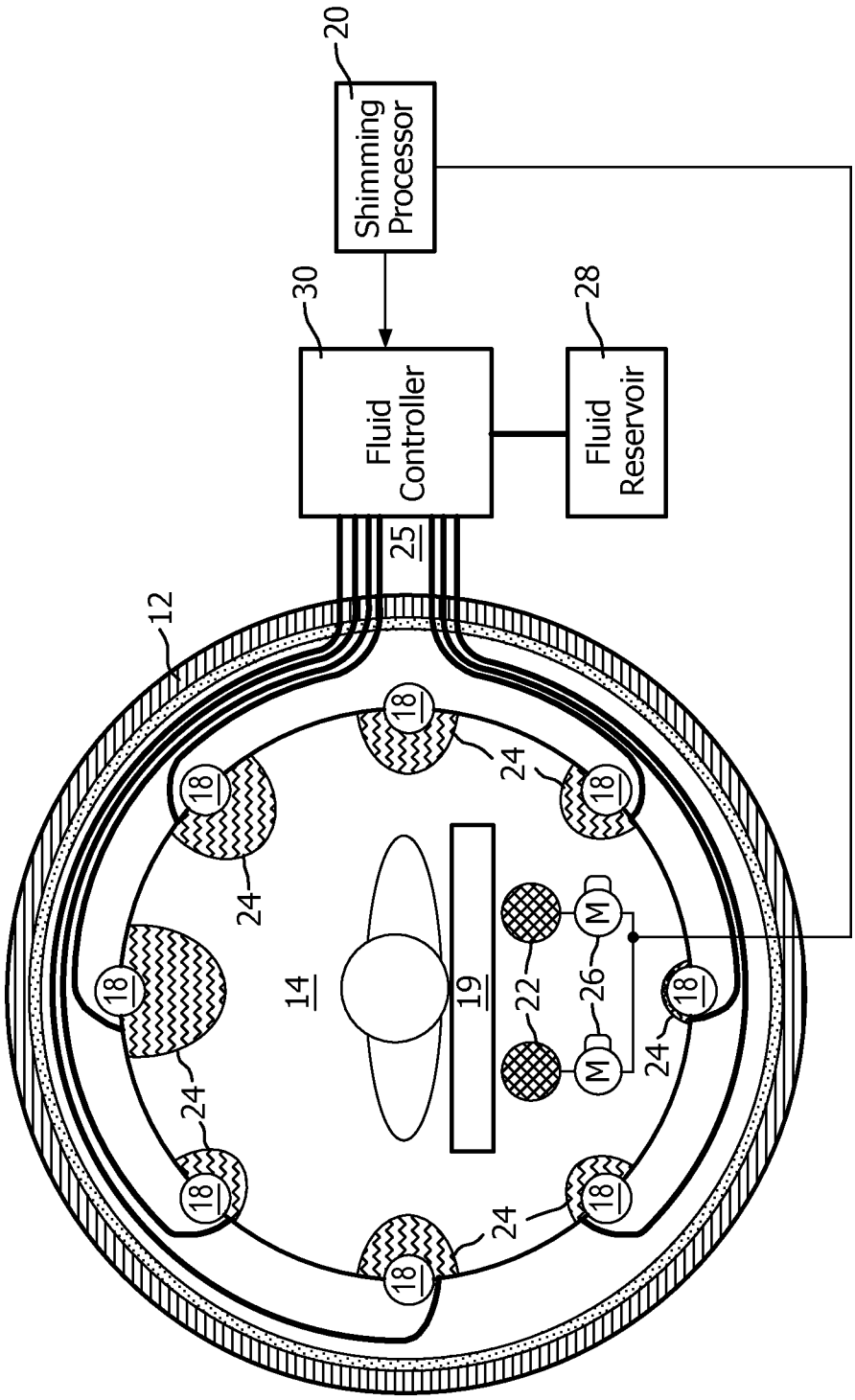

20
Shimming Processor
30
Fluid Controller
28
Fluid Reservoir
25
12
18
24
14
19
22
26
M

FIG. 2

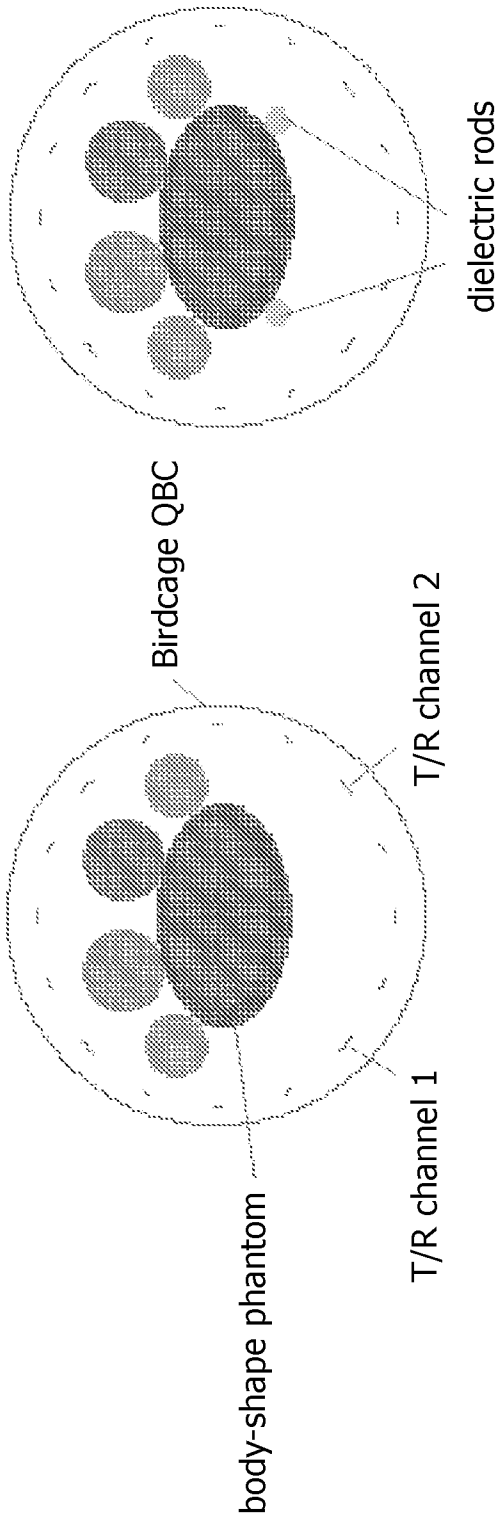
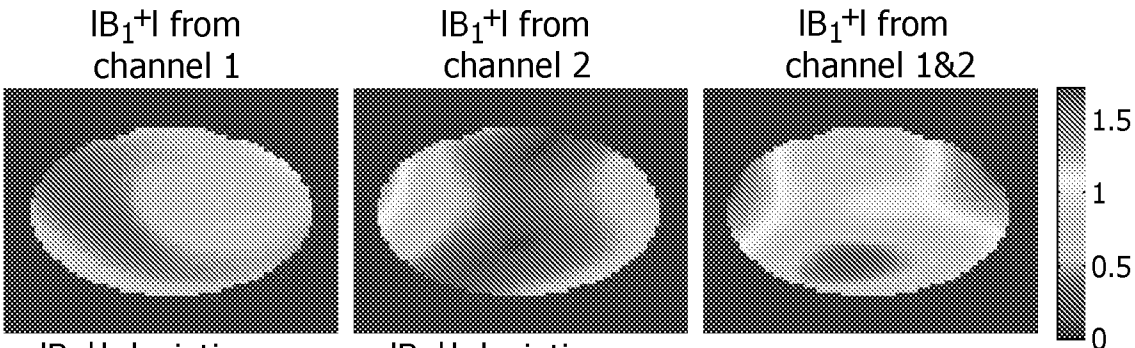

dielectric rods
Birdcage QBC
T/R channel 2
T/R channel 1
body-shape phantom

FIG. 3

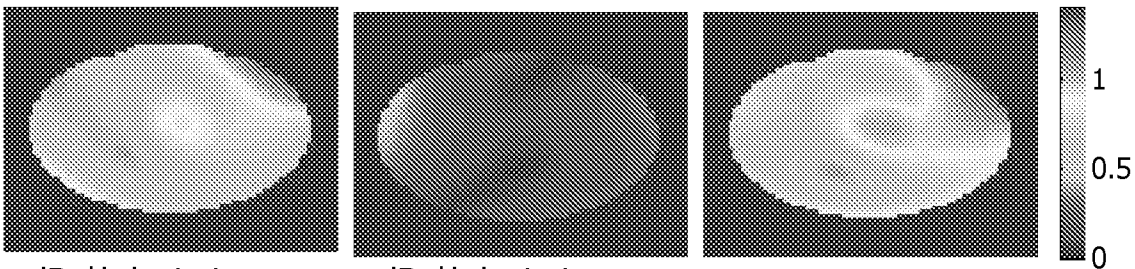


$|B_1^+|$ deviation = 0.25

$|B_1^+|$ deviation = 0.52

V_1/V_2 = 0dB, θ = 0º $|B_1^+|$ deviation = 0.33

FIG. 4a

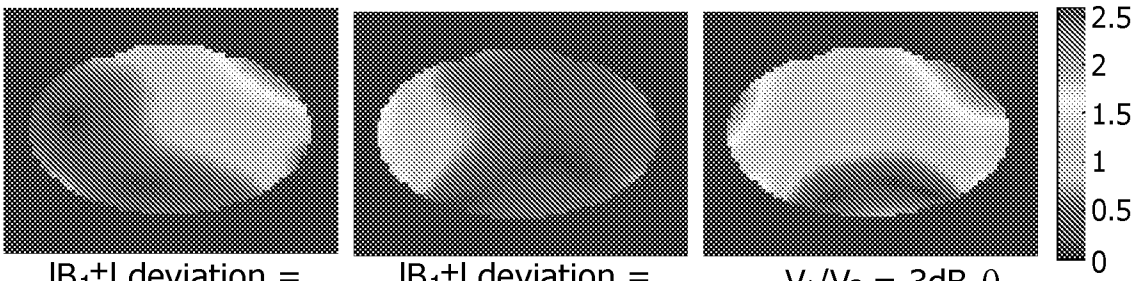


$|B_1^+|$ deviation = 0.25

$|B_1^+|$ deviation = 0.52

V_1/V_2 = 10dB, θ = 40º $|B_1^+|$ deviation = 0.23 (-30%)

FIG. 4b

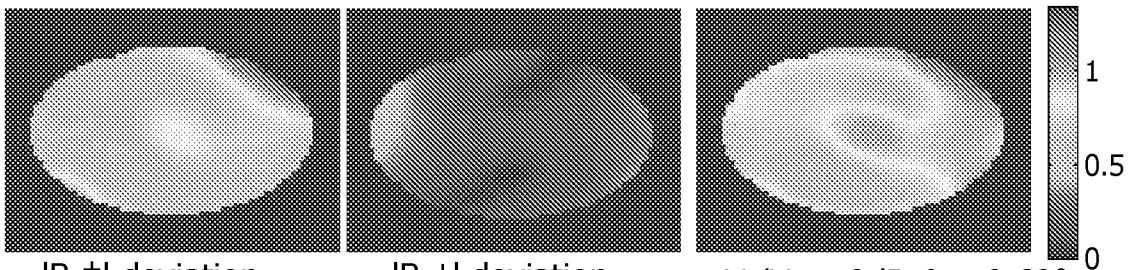


$|B_1^+|$ deviation = 0.60

$|B_1^+|$ deviation = 0.72

V_1/V_2 = 3dB, θ = 100º $|B_1^+|$ deviation = 0.38

FIG. 4c



$|B_1^+|$ deviation = 0.24

$|B_1^+|$ deviation = 0.55

V_1/V_2 = 9dB, θ = 0.60º $|B_1^+|$ deviation = 0.19 (-42%)

FIG. 4d

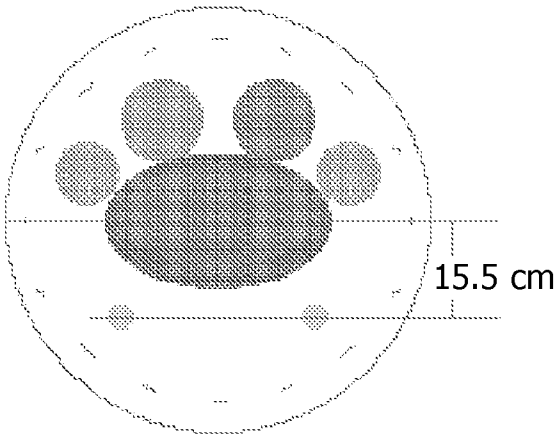
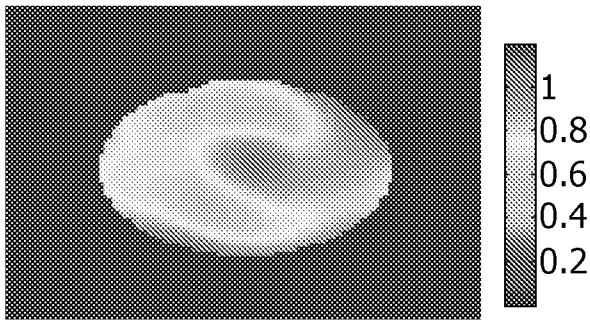


FIG. 5a



V_1/V_2 = 9dB, θ = 40º
$|B_1^+|$ deviation = 0.16 (-52%)

$|B_1^+|_{max}/|B_1^+|_{min}$ = 2.2

FIG. 5b

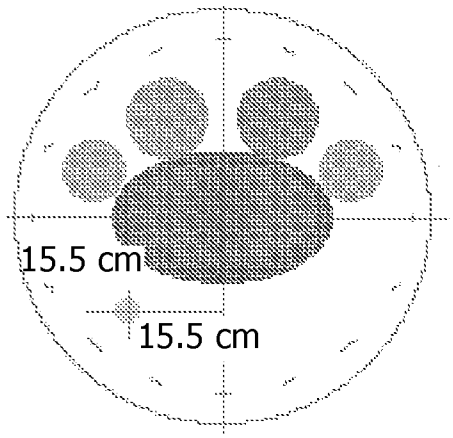
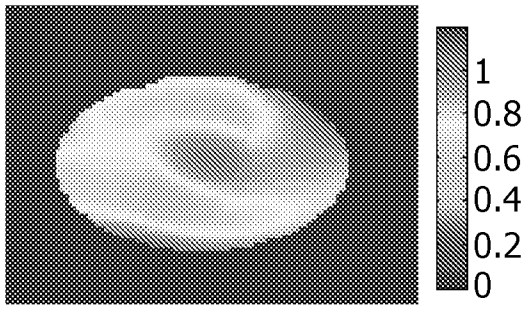


FIG. 5c



V_1/V_2 = 8dB, θ = 60º $|B_1^+|$
deviation = 0.16 (-52%)

$|B_1^+|_{max}/|B_1^+|_{min}$ = 2.4

FIG. 5d

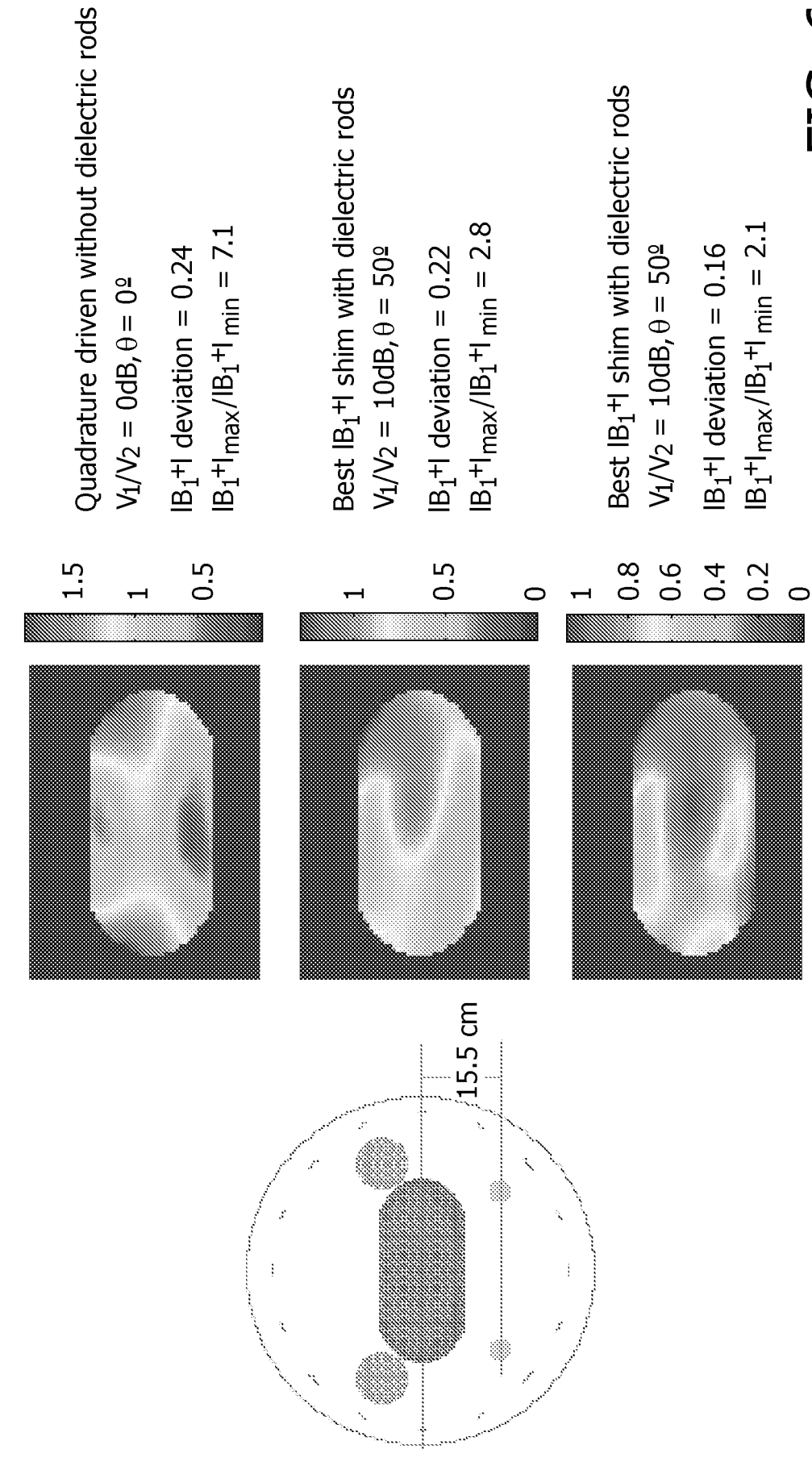

Quadrature driven without dielectric rods
V_1/V_2 = 0dB, θ = 0º
$|B_1^+|$ deviation = 0.24
$|B_1^+|_{max}/|B_1^+|_{min}$ = 7.1
1.5
1
0.5
Best $|B_1^+|$ shim with dielectric rods
V_1/V_2 = 10dB, θ = 50º
$|B_1^+|$ deviation = 0.22
$|B_1^+|_{max}/|B_1^+|_{min}$ = 2.8
1
0.5
0
Best $|B_1^+|$ shim with dielectric rods
V_1/V_2 = 10dB, θ = 50º
$|B_1^+|$ deviation = 0.16
$|B_1^+|_{max}/|B_1^+|_{min}$ = 2.1
1
0.8
0.6
0.4
0.2
0
15.5 cm

FIG. 6

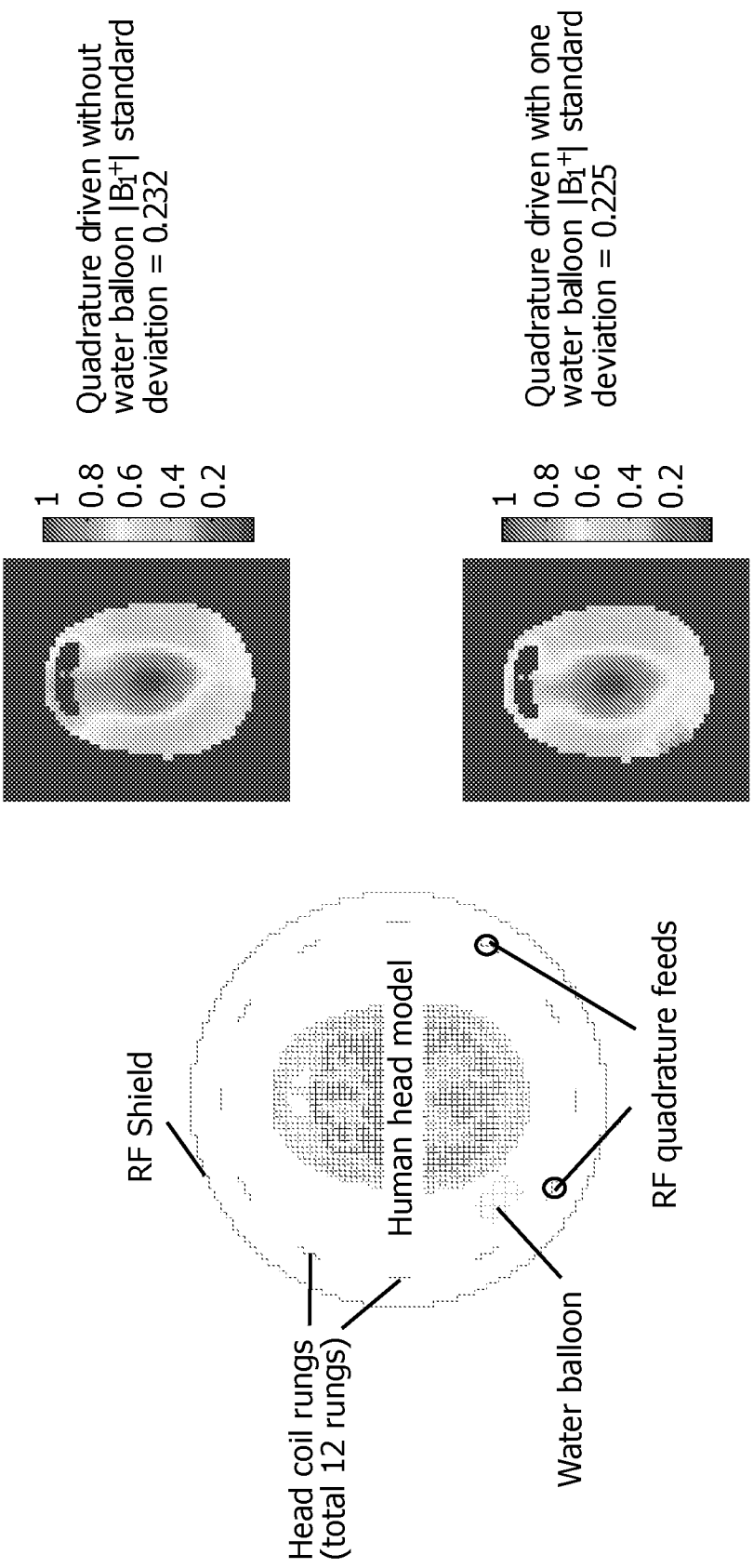

Quadrature driven without water balloon $|B_1^+|$ standard deviation = 0.232
1
0.8
0.6
0.4
0.2
Quadrature driven with one water balloon $|B_1^+|$ standard deviation = 0.225
1
0.8
0.6
0.4
0.2
RF Shield
Human head model
RF quadrature feeds
Head coil rungs (total 12 rungs)
Water balloon

FIG. 7

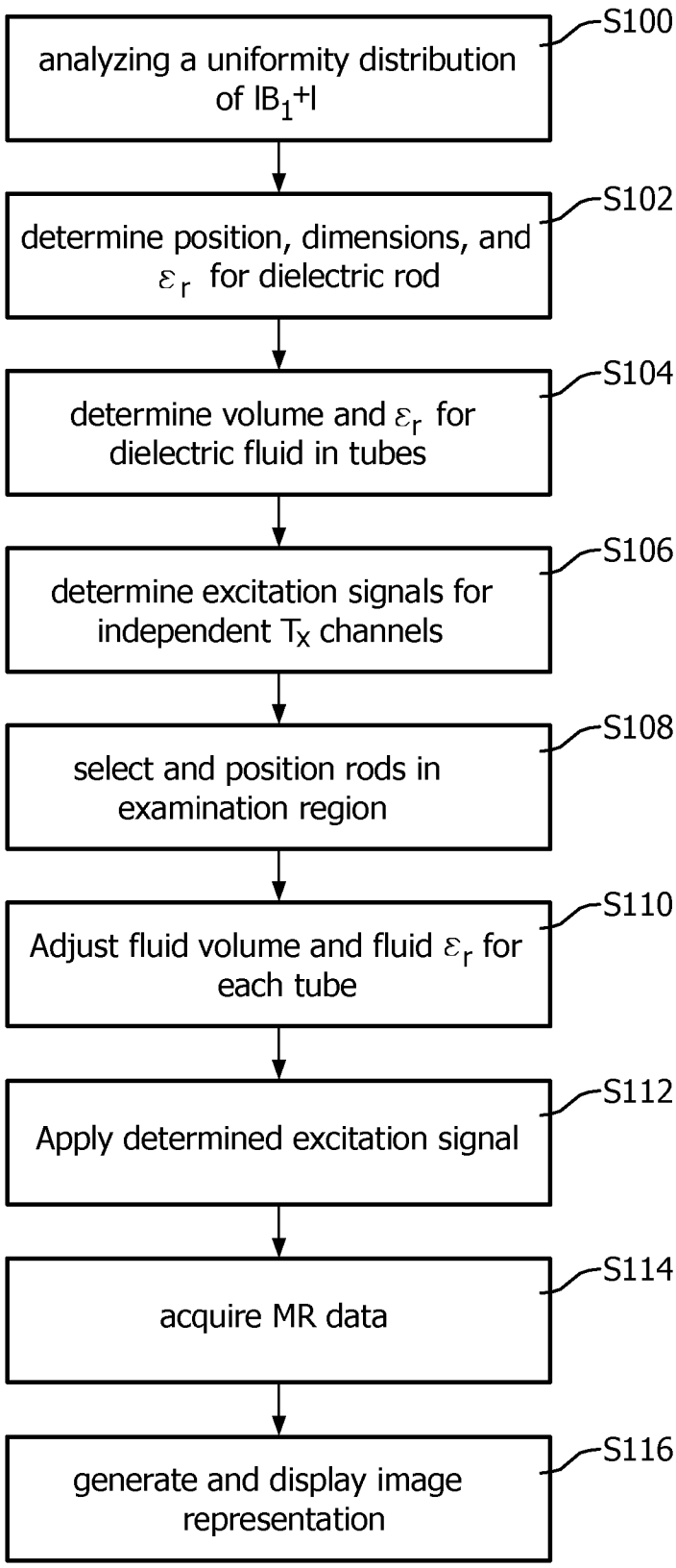

analyzing a uniformity distribution of $|B_1^+|$
S100
determine position, dimensions, and ε_r for dielectric rod
S102
determine volume and ε_r for dielectric fluid in tubes
S104
determine excitation signals for independent T_X channels
S106
select and position rods in examination region
S108
Adjust fluid volume and fluid ε_r for each tube
S110
Apply determined excitation signal
S112
acquire MR data
S114
generate and display image representation
S116

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/055450

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/34 G01R33/54
ADD.

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)
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)
EPO-Internal, COMPENDEX, BIOSIS, EMBASE, INSPEC, MEDLINE, 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	YANG QING X ET AL: "Manipulation of image intensity distribution at 7.0 T: passive RF shimming and focusing with dielectric materials.", JOURNAL OF MAGNETIC RESONANCE IMAGING : JMRI JUL 2006 LNKD- PUBMED:16755543, vol. 24, no. 1, July 2006 (2006-07), pages 197-202, XP002524604, ISSN: 1053-1807	1-8, 10-17,19
A	the whole document	9,18,20
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
6 March 2012	14/03/2012

Name and mailing address of the ISA/	Authorized officer
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3

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/055450

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NEUFELD A ET AL: "Dielectric inserts for sensitivity and RF magnetic field enhancement in NMR volume coils", JOURNAL OF MAGNETIC RESONANCE SEPTEMBER 2009 ACADEMIC PRESS INC. USA, vol. 200, no. 1, September 2009 (2009-09), pages 49-55, XP026587554, DOI: DOI:10.1016/J.JMR.2009.06.001 the whole document --- HAINES K ET AL: "New high dielectric constant materials for tailoring the B1<+> distribution at high magnetic fields", JOURNAL OF MAGNETIC RESONANCE, ACADEMIC PRESS, ORLANDO, FL, US, vol. 203, no. 2, 1 April 2010 (2010-04-01) , pages 323-327, XP026969831, ISSN: 1090-7807 [retrieved on 2010-03-16] the whole document --- US 2005/110493 A1 (FEIWEIER THORSTEN [DE] ET AL) 26 May 2005 (2005-05-26) paragraph [0016] - paragraph [0025] --- US 5 865 177 A (SEGAWA TORU [JP]) 2 February 1999 (1999-02-02) column 5, line 17 - line 44 ---	1,14 1,14 1,14 1,14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2011/055450

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2005110493 A1	26-05-2005
US 5865177 A	02-02-1999	NONE	