US007719269B2

(12) **United States Patent**
Petersson et al.

(10) **Patent No.: US 7,719,269 B2**
(45) **Date of Patent: May 18, 2010**

(54) **SYSTEM AND METHOD FOR FAST MR IMAGING OF METABOLITES AT SELECTIVE EXCITATION FREQUENCIES**

(75) Inventors: **Stefan Petersson**, Helsingborg (SE); **Sven Månsson**, Bjärred (SE)

(73) Assignee: **General Electric Company**, Schenectady, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 471 days.

(21) Appl. No.: **11/562,391**

(22) Filed: **Nov. 21, 2006**

(65) **Prior Publication Data**

US 2008/0116893 A1 May 22, 2008

(51) **Int. Cl.**
G01V 3/00 (2006.01)

(52) **U.S. Cl.** **324/307**; 324/309

(58) **Field of Classification Search** 324/307, 324/309

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,677,628 A * 10/1997 Watanabe et al. 324/309
6,304,084 B1 * 10/2001 Star-Lack et al. 324/307
6,806,706 B2 * 10/2004 Gurr 324/307
7,034,530 B2 * 4/2006 Ahluwalia et al. 324/309
7,042,214 B2 * 5/2006 Cunningham et al. 324/307
2004/0171928 A1 9/2004 Petersson et al.

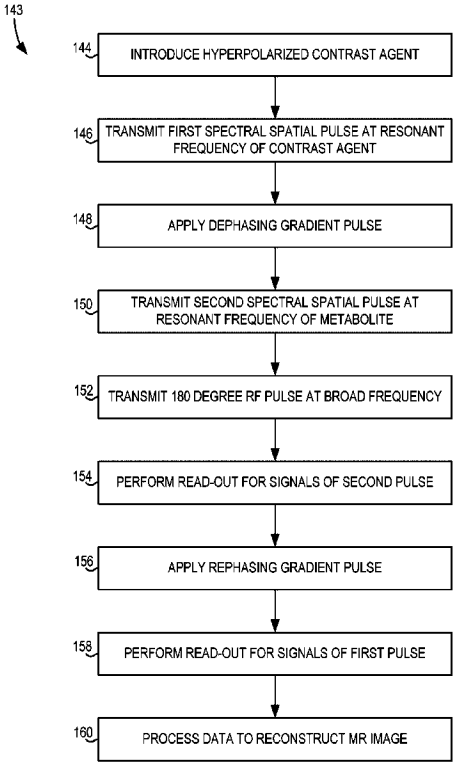
* cited by examiner

Primary Examiner—Louis M Arana
(74) *Attorney, Agent, or Firm*—Ziolkowski Patent Solutions Group, SC

(57) **ABSTRACT**

A system and method are provided for imaging multiple substances, such as contrast agents and metabolites in vivo, with selective excitation frequencies. A first substance is excited with a frequency selective pulse, then a second substance is excited with another frequency selective pulse. The signals resulting from these pulses are acquired in an order reversed from the order in which the pulses were applied. In some embodiments, more than two substances may be imaged. The system and method thus provide for quick and efficient utilization of the magnetization of multiple substances for spectral-spatial imaging.

7 Claims, 6 Drawing Sheets



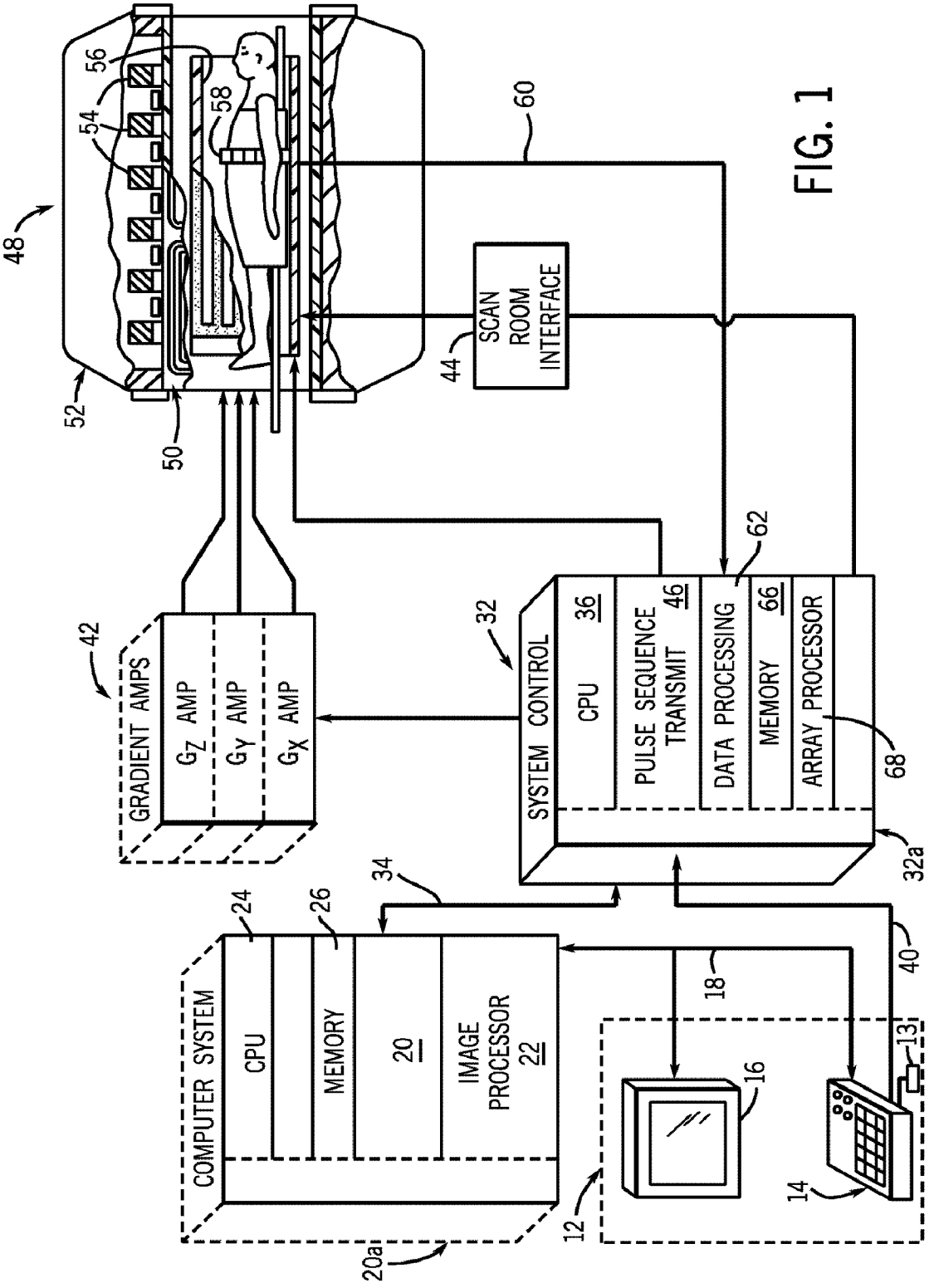

48
56
54
58
60
52
50
SCAN ROOM INTERFACE
44
42
GRADIENT AMPS
G_Z AMP
G_Y AMP
G_X AMP
32
SYSTEM CONTROL
CPU 36
PULSE SEQUENCE TRANSMIT 46
DATA PROCESSING
MEMORY 66
ARRAY PROCESSOR
62
68
32a
34
24
26
COMPUTER SYSTEM
CPU
MEMORY
20
IMAGE PROCESSOR 22
20a
18
40
16
13
14
12

FIG. 1

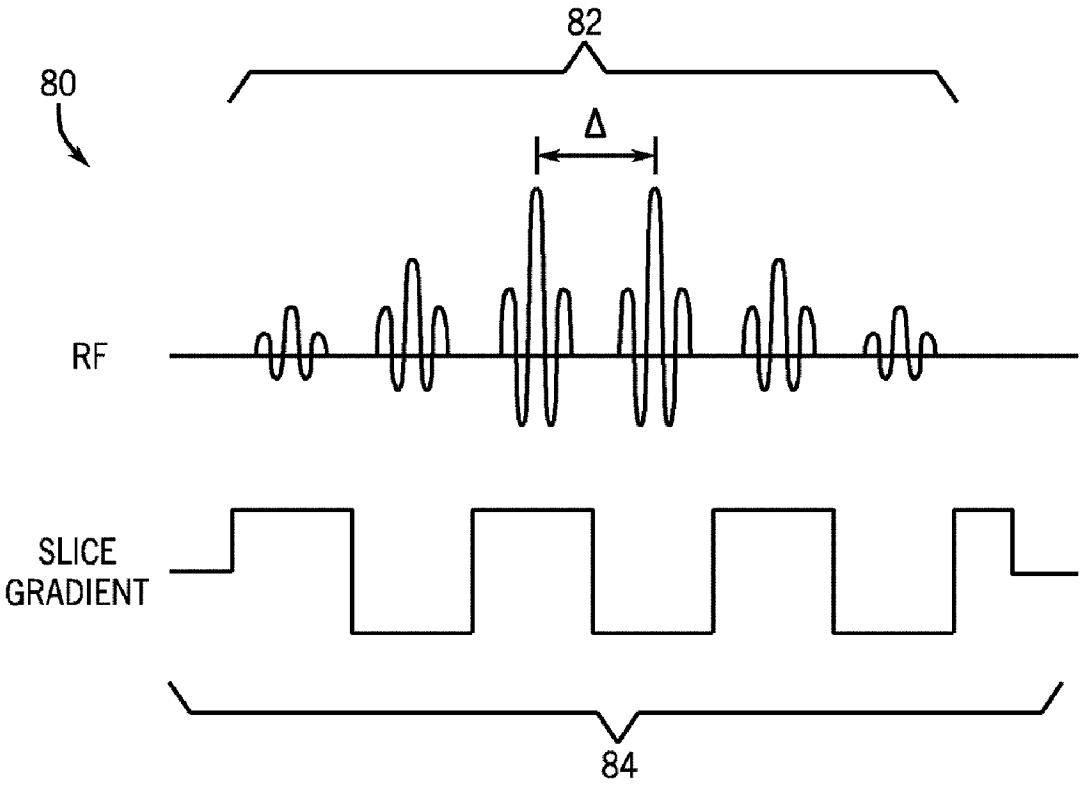

82
80
Δ
RF
SLICE
GRADIENT
84

FIG. 2

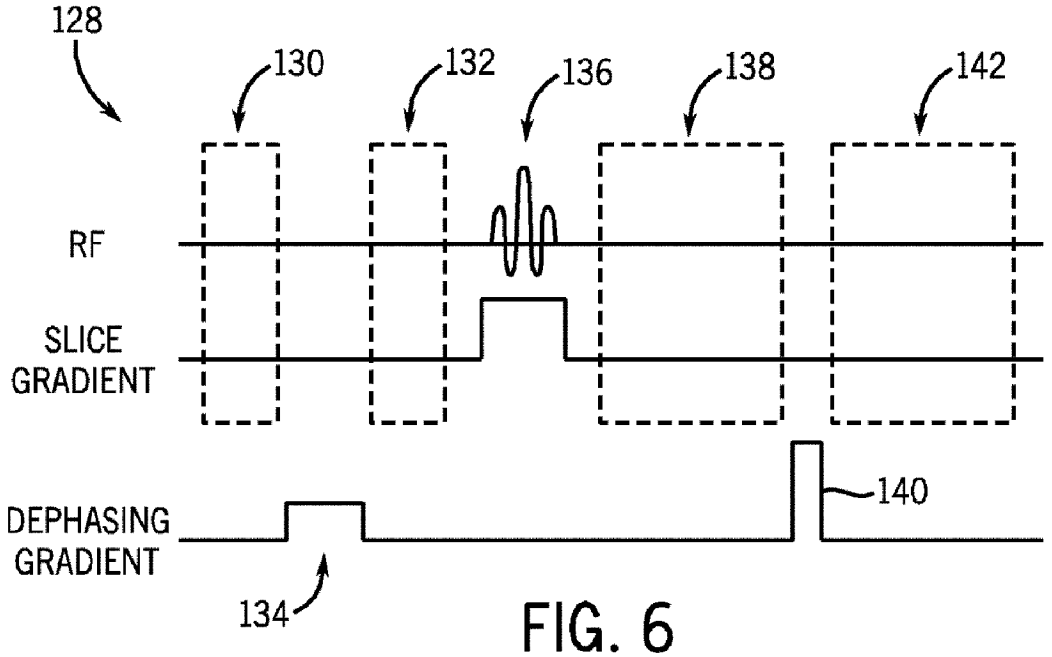

128
130
132
136
138
142
RF
SLICE
GRADIENT
140
DEPHASING
GRADIENT
134

FIG. 6

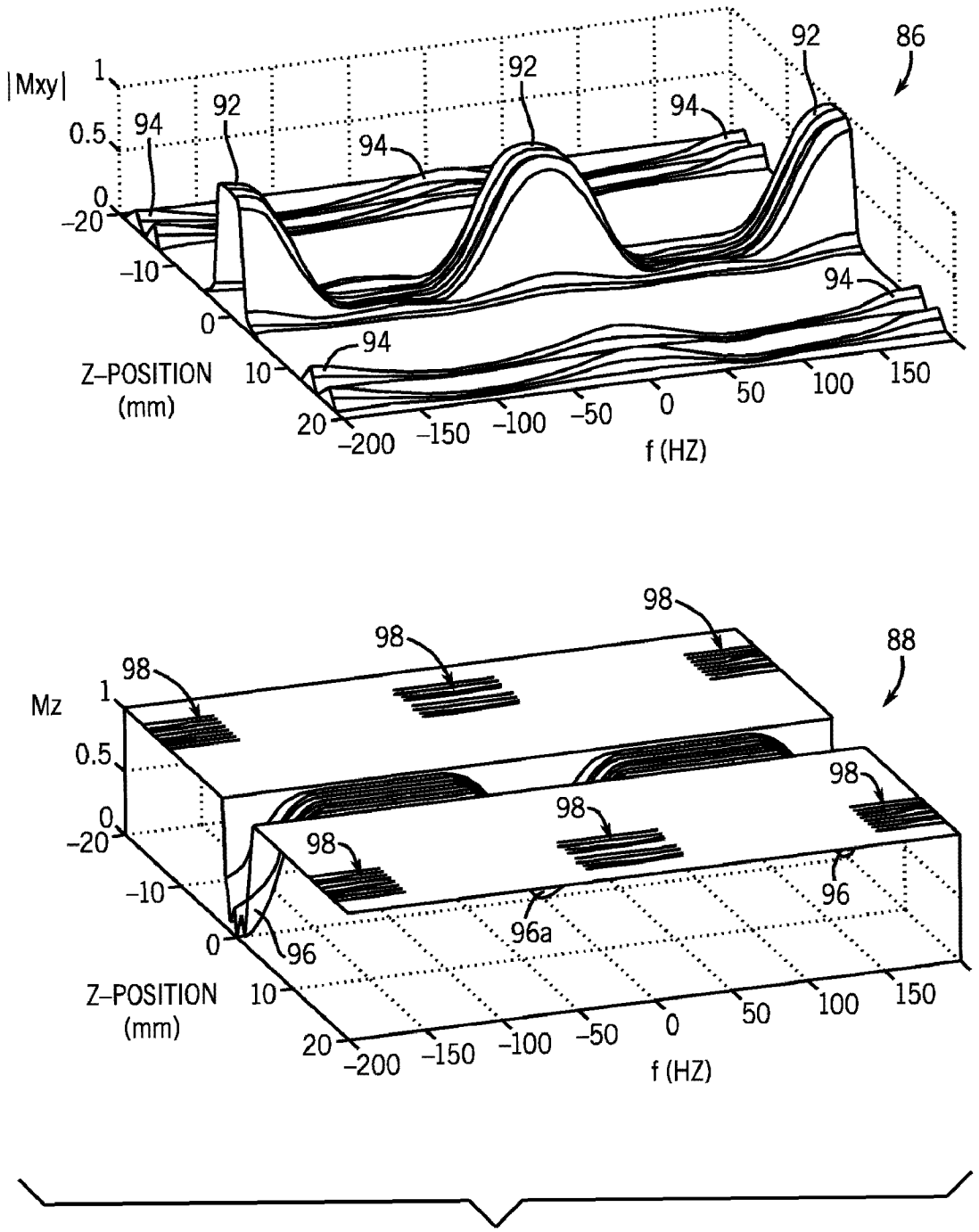

|Mxy|
1
0.5
0
92
94
86
Z-POSITION
(mm)
-20
-10
0
10
20
-200
-150
-100
-50
0
50
100
150
f (HZ)
Mz
98
88
96
96a

FIG. 3

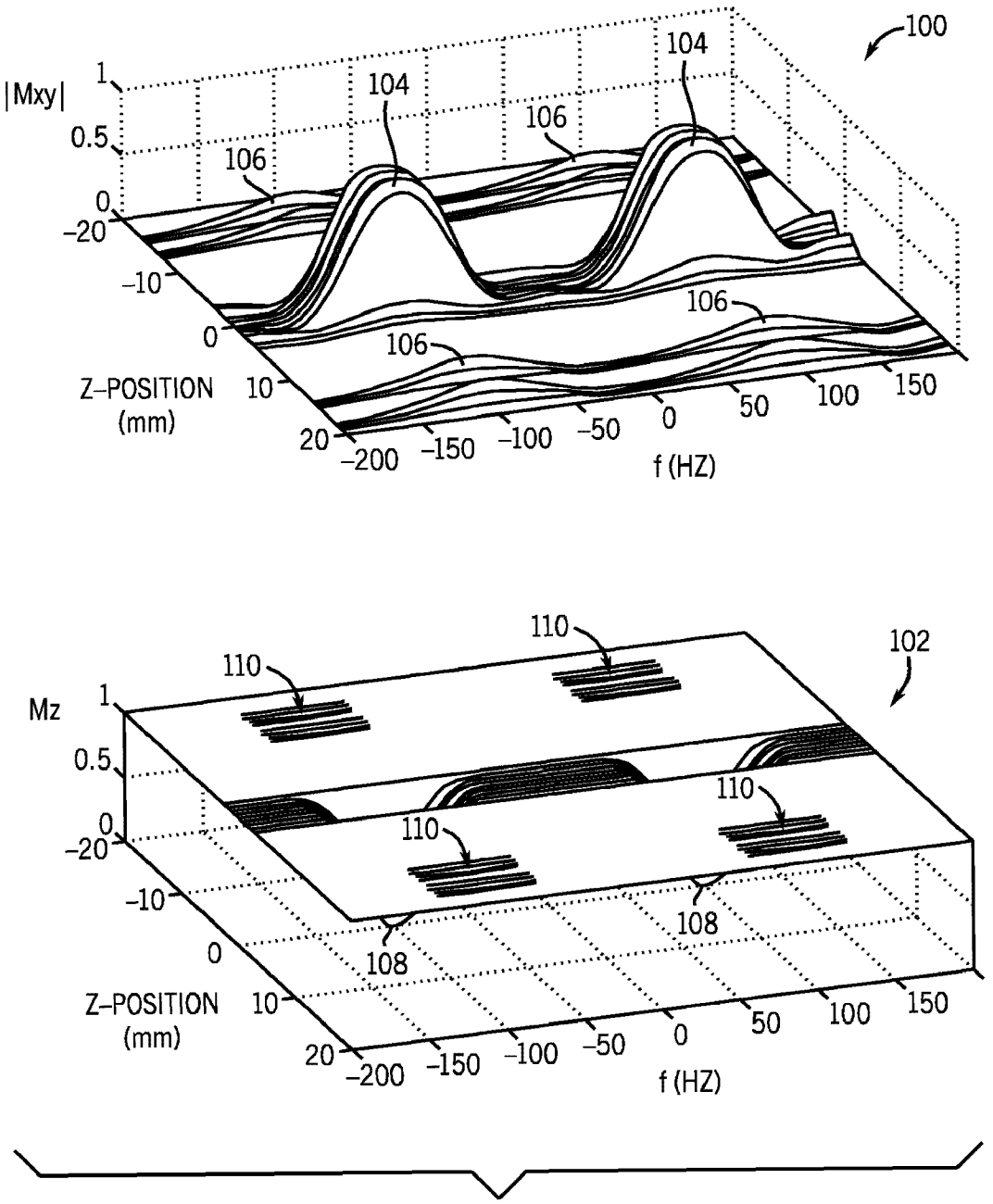

100
|Mxy|
1
0.5
0
104
106
Z-POSITION
(mm)
-20
-10
0
10
20
-200
-150
-100
-50
0
50
100
150
f (HZ)
102
Mz
110
108

FIG. 4

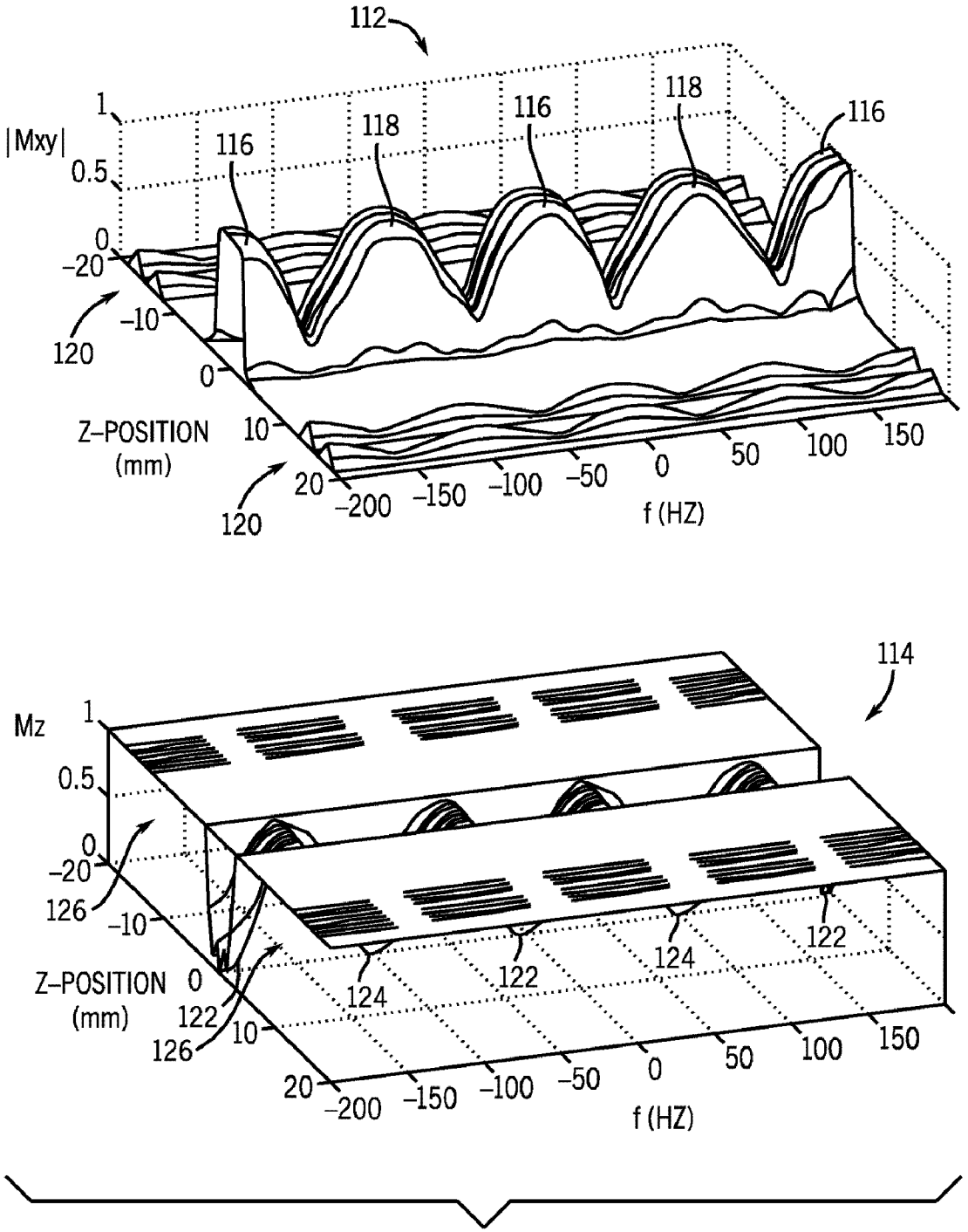

112
|Mxy|
1
0.5
0
116
118
116
118
116
-20
-10
0
10
20
120
120
Z-POSITION
(mm)
-200
-150
-100
-50
0
50
100
150
f (HZ)
114
Mz
1
0.5
0
-20
-10
0
10
20
126
126
Z-POSITION
(mm)
122
124
122
124
122
-200
-150
-100
-50
0
50
100
150
f (HZ)

FIG. 5

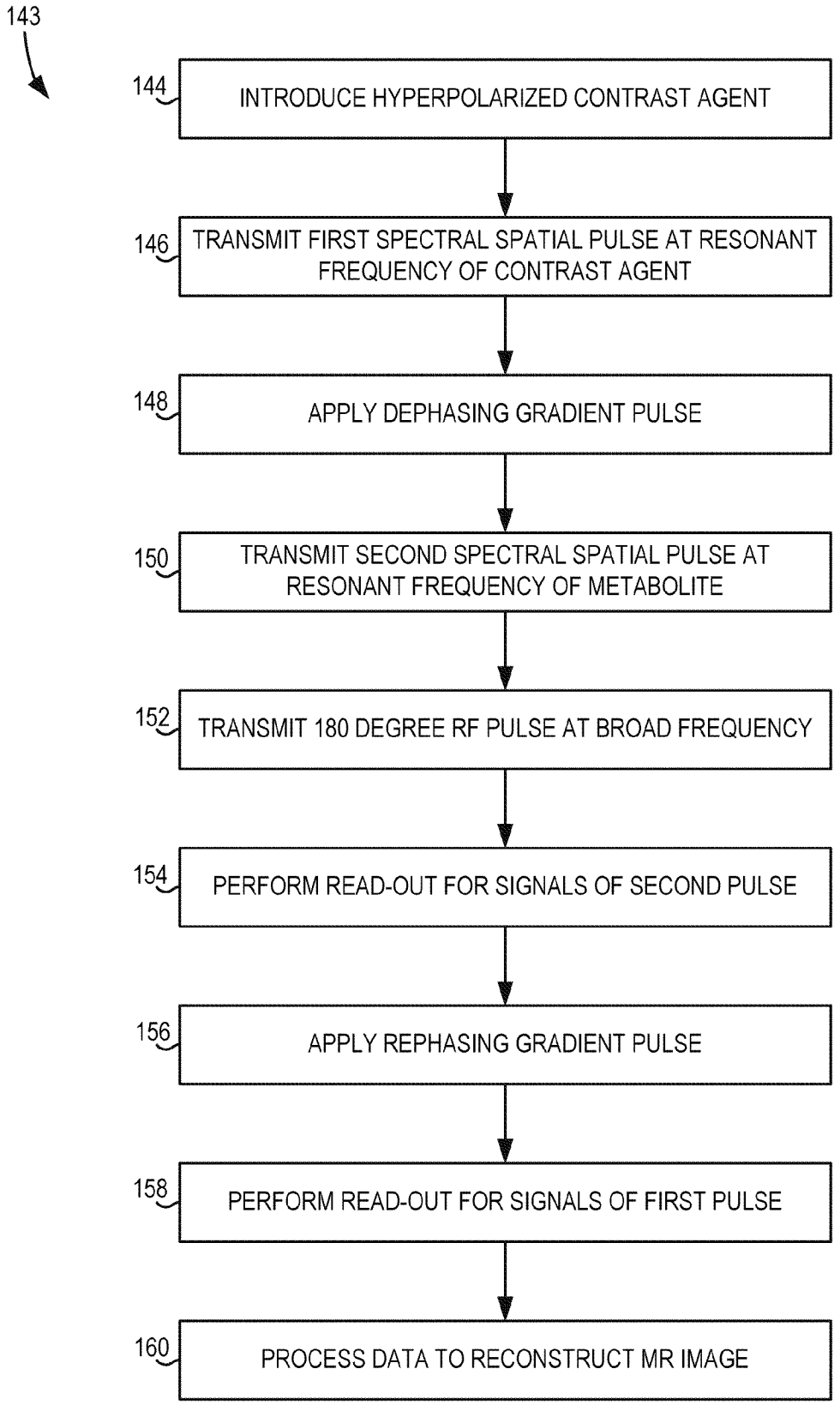

143
144
INTRODUCE HYPERPOLARIZED CONTRAST AGENT
146
TRANSMIT FIRST SPECTRAL SPATIAL PULSE AT RESONANT FREQUENCY OF CONTRAST AGENT
148
APPLY DEPHASING GRADIENT PULSE
150
TRANSMIT SECOND SPECTRAL SPATIAL PULSE AT RESONANT FREQUENCY OF METABOLITE
152
TRANSMIT 180 DEGREE RF PULSE AT BROAD FREQUENCY
154
PERFORM READ-OUT FOR SIGNALS OF SECOND PULSE
156
APPLY REPHASING GRADIENT PULSE
158
PERFORM READ-OUT FOR SIGNALS OF FIRST PULSE
160
PROCESS DATA TO RECONSTRUCT MR IMAGE

FIG. 7

SYSTEM AND METHOD FOR FAST MR IMAGING OF METABOLITES AT SELECTIVE EXCITATION FREQUENCIES

BACKGROUND OF THE INVENTION

The present invention relates generally to a system and method for magnetic resonance (MR) imaging, and more particularly, to an MR system and pulse sequence which slice-selectively excites multiple frequencies for quick and efficient imaging. Spectral-spatial radio frequency (RF) pulses may be used to create magnetization in specific frequency profiles without significantly affecting neighboring slices or nearby frequency ranges. The signals resulting from such pulses are then read in an order reversed from the order in which the pulses were applied.

When a substance such as human tissue is subjected to a uniform magnetic field (polarizing field B_0), the individual magnetic moments of the spins in the tissue attempt to align with this polarizing field, but precess about it in random order at their characteristic Larmor frequency. If the substance, or tissue, is subjected to a magnetic field (excitation field B_1) which is in the x-y plane and which has a frequency near the Larmor frequency, the net aligned moment, or "longitudinal magnetization", M_z, may be rotated, or "tipped", into the x-y plane to produce a net transverse magnetic moment M_t. A signal is emitted by the excited spins after the excitation signal B_1 is terminated and this signal may be received and processed to form an image.

When utilizing these signals to produce images, magnetic field gradients (G_x, G_y, and G_z) are employed. Typically, the region to be imaged is scanned by a sequence of measurement cycles in which these gradients vary according to the particular localization method being used. The set of received nuclear magnetic resonance (NMR) signals resulting from a scan sequence are digitized and sent to a data processing unit for image reconstruction using one of many well known reconstruction techniques. It is desirable that the imaging process, from data acquisition to reconstruction, be performed as quickly as possible for improved patient comfort and throughput.

For some procedures and investigations, it is also desirable for MR images to display spectral information in addition to spatial information. The traditional method for creating such images is known as "chemical shift imaging" (CSI). CSI has been employed to monitor metabolic and other internal processes of patients, including imaging hyperpolarized substances such as 13-C labeled contrast agents and metabolites thereof. The hyperpolarization of contrast agents tends to have a very limited lifetime; typical T1 lifetimes are on the order of a few minutes in vivo.

However, CSI, as a sequence for imaging hyperpolarized substances, has some drawbacks which limit available signal-to-noise ratio and thus image quality. For example, CSI tends to acquire data slowly, considering the short lifetimes of the increased magnetization of hyperpolarized substances. In addition, CSI typically uses a large number of RF excitations. Each excitation irretrievably destroys the magnetization of hyperpolarized substances. Additionally, MR procedures which require very fast or periodic data acquisition (such as cardiac imaging, or metabolic imaging of the heart) are difficult to perform with CSI sequences. CSI typically takes about 15 seconds to complete, whereas cardiac and related metabolic imaging should be completed within a few heartbeats or a few seconds.

Non-CSI techniques for imaging hyperpolarized substances without acquiring spectral information include

single-shot techniques (e.g. a strong RF pulse which destroys all magnetization and attempts to acquire all data for multiple metabolites at once) or imaging with a large number of small flip-angle RF pulses (e.g. multiple excitations with flip angles on the order of 1 or 2 degrees). These approaches excite all frequency ranges for metabolites of interest simultaneously, destroying hyperpolarization of all metabolites with each pulse. In addition, when pulses of lower flip angle are used, a lower signal-to-noise ratio (SNR), and hence a lower image resolution, is the result.

It would therefore be desirable to have a system and method which overcomes the aforementioned drawbacks of MR imaging with spectral information and hyperpolarization. Specifically, it would be desirable to excite and image hyperpolarized agents and metabolites thereof within a short time, while efficiently utilizing the full magnetization of each substance and acquiring spectral information.

BRIEF DESCRIPTION OF THE INVENTION

A system and method for slice-selectively exciting resonant frequencies for substances of interest are provided. Such substances may include contrast agents and metabolites, such as 13-C contrast agents. In this regard, a number of spectral-spatial RF pulses may be emitted to excite frequencies in a subject of interest. The signals resulting from these pulses are read in an order reversed from the order in which the pulses were applied in one or more of several well-known read-out sequences.

In accordance with one aspect of the present invention, an MR system includes a plurality of gradient coils, an RF coil assembly, and a system control. The system control is programmed to cause the RF coil assembly to emit two spectral-spatial RF pulses, then detect the resulting MR signals from the second pulse before detecting the MR signals from the first pulse.

In accordance with another aspect of the invention, a method for MR imaging is disclosed. The method includes individually exciting the resonant frequencies of two or more metabolites at one flip angle, then simultaneously exciting the resonant frequencies of the metabolites at a second flip angle. After excitation, the resulting MR signals of the metabolites are detected.

According to a further embodiment, a sequence of instructions is stored on a computer readable storage medium. When the instructions are executed by a computer, the computer is caused to request transmission of a spectral-spatial pulse at one frequency, transmission of a dephasing gradient pulse for that frequency, transmission of another spectral-spatial pulse at another frequency, and then transmission of an RF pulse over a frequency range including both frequencies.

Various other features and advantages will be made apparent from the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings illustrate embodiments presently contemplated for carrying out the invention.

In the drawings:

FIG. **1** is a schematic block diagram of an exemplary MR imaging system incorporating an embodiment of the present invention.

FIG. **2** is a graph of an exemplary RF pulse train and slice gradient waveform of a spectral-spatial pulse in accordance with an embodiment of the present invention.

FIG. **3** is a 3-D graph of an excitation profile for a spectral-spatial pulse in accordance with an embodiment of the present invention.

FIG. **4** is a 3-D graph of an excitation profile for a spectral-spatial pulse exciting a different frequency band than that of FIG. **3**, in accordance with an embodiment of the present invention.

FIG. **5** is a 3-D graph of an excitation profile for the spectral-spatial pulses of FIG. **3** and FIG. **4** combined, in accordance with an embodiment of the present invention.

FIG. **6** is a graph of an imaging sequence in accordance with an embodiment of the present invention.

FIG. **7** is a flowchart illustrating a technique for MR imaging of metabolites at selective excitation frequencies in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, the major components of an example magnetic resonance imaging (MRI) system **10** incorporating an embodiment of the present invention are shown. The operation of the system may be controlled from an operator console **12** which includes a keyboard or other input device **13**, a control panel **14**, and a display screen **16**. The console **12** communicates through a link **18** with a separate computer system **20** that enables an operator to control the production and display of images on the display screen **16**. The computer system **20** includes a number of modules which communicate with each other through a backplane **20***a*. These include an image processor module **22**, a CPU module **24** and a memory module **26**, which may include a frame buffer for storing image data arrays. The computer system **20** may also be connected to permanent or back-up memory storage, a network, or may communicate with a separate system control **32** through a high speed serial link **34**. The input device **13** can include a mouse, keyboard, track ball, touch activated screen, light wand, or any similar or equivalent input device, and may be used for interactive geometry prescription.

The system control **32** includes a set of modules connected together by a backplane **32***a* and connected to the operator console **12** through a serial link **40**. It is through link **40** that the system control **32** receives commands from the operator to indicate the scan sequence that is to be performed. The pulse sequence transmit module **38** commands the scanner components to carry out the desired scan sequence, by sending instructions, commands, and/or requests describing the timing, strength and shape of the RF pulses and pulse sequences to be produced, to correspond to the timing and length of the data acquisition window. The system control **32** also connects to a set of gradient amplifiers **42**, to indicate the timing and shape of the gradient pulses that are produced during the scan. The system control **32** may also receive patient data from a scan room interface **44**, which may relate data from a user or from a number of different sensors connected to the patient, such as ECG signals from electrodes attached to the patient.

The gradient waveform instructions produced by system control **32** are sent to the gradient amplifier system **42** having Gx, Gy, and Gz amplifiers. Amplifiers **42** may be external of scanner **48**, or may be integrated therein. Each gradient amplifier excites a corresponding physical gradient coil in a gradient coil assembly generally designated **50** to produce the magnetic field gradients used for spatially encoding acquired signals. The gradient coil assembly **50** forms part of a magnet assembly **52** which includes a polarizing magnet **54** and an RF coil assembly **56**, **58**. RF coil assembly may include a whole-body RF transmit coil **56**, surface or parallel imaging coils **58**, or both. The coils **56**, **58** of the RF coil assembly may be configured for both transmitting and receiving, or for transmit-only or receive-only. A pulse generator (not shown) integrated into the scanner equipment **48** produces RF pulses in accordance with the instructions of the pulse sequence transmit module **46** which are amplified and coupled to the RF coil **56** for transmission. Alternatively, RF transmit coil **56** may be replaced or augmented with surface and/or parallel transmit coils, such as coil **58**. Similarly, the resulting signals emitted by the excited nuclei in the patient may be sensed by separate receive coils, such as parallel coils or surface coils **58**, and are then sent over a data link **60**. The MR signals are demodulated, filtered, and digitized in the data processing section **62** of the system control **32**.

A scan is complete when an array of raw k-space data has been acquired in the memory module **66**. This raw k-space data is rearranged into separate k-space data arrays for each image to be reconstructed, and each of these is input to an array processor **68** which operates to Fourier transform the data into an array of image data. This image data is conveyed through the serial link **34** to the computer system **20** where it is stored in memory **26**. In response to commands received from the operator console **12**, this image data may be archived in long term storage or may be further processed by the image processor **22** and conveyed to the operator console **12** and presented on the display **16**.

Referring now to FIG. **2**, an exemplary spectral-spatial type excitation pulse **80** is depicted. As discussed above, spectral-spatial imaging is a type of imaging in which spectral data regarding the type of substance being imaged is combined with the typical slice selection of common MR imaging. Excitation pulse **80** includes a number of RF sub-elements **82**. As shown, these elements **82** represent periodic sinc functions of gradually increasing, then decreasing amplitudes. However, it is recognized that RF sub-elements **82** may take many forms other than merely sinc functions, such as Gaussian waveforms. The frequency of the RF elements **82** may be selected to correspond to the resonant frequency of a particular substance of interest, for spectral encoding. For example, the resonant frequency of nuclei of a hyperpolarized substance may be targeted by pulse **80**.

Along with the RF pulses **82**, a slice encoding gradient **84** is applied. Slice encoding gradient **84** is a periodic gradient of alternating sign. In combination, RF elements **82** and gradient **84** allow for slice-selective excitation within a specific frequency range. The spectral excitation profile of the pulse (to be described below) is periodic with a periodicity of $1/\Delta$ Hz, where Δ represents the time distance between the sub-elements of the RF waveform **80**. In a preferred embodiment, excitation pulse **80** is applied to effect approximately a 90 degree total flip angle, though it is contemplated that other flip angles are also suitable. For example, the polarization and sensitivity to RF magnetization destruction of a contrast agent, the number of excitations desired, or the desired image resolution may affect the strength of the pulse to be applied.

Referring now to FIG. **3**, the effects upon magnetization of an arbitrary spectral-spatial pulse (such as described with reference to FIG. **2**) are shown. The upper plot **86** shows transverse magnetization Mxy and the lower plot **88** shows longitudinal magnetization Mz. The horizontal axes of the plots **86**, **88** represent spectral frequency, the front-to-back axes represent geometric position along the z axis, and the vertical axes show magnetization. As shown, the primary transverse magnetization **92** is centered along the position marked as 0 mm along the z-position axis. Along the spectral axis, the magnetization **92** is periodic, centered at 0 Hz. As

discussed above, the periodicity of magnetization **92** is dependant upon the A component of the spectral-spatial pulse applied. Thus, a desired period 1/Δ Hz may be attained by altering this characteristic of the spectral-spatial pulse. Magnetization **94** outside the primary slice is relatively weak in comparison. Likewise, magnetization at spectral positions 100 Hz on either side of primary magnetization **92** is nearly non-existent.

Lower plot **88** of FIG. **3** shows converse effects upon longitudinal magnetization. A corresponding primary decrease in longitudinal magnetization **96** is centered at the position marked as 0 mm along the z-position (front-to-back) axis. The primary reduction in magnetization **96** is periodic, centered at 0 Hz, as is the case with transverse magnetization. The period of the primary longitudinal magnetization reduction **96** is also 1/Δ Hz, dependant upon the spectral-spatial pulse applied. Magnetization at approximately 100 Hz on either side of primary magnetization reduction **96** remains at the initial strength (i.e. essentially unchanged by application of the spectral-spatial pulse). Likewise, magnetization **98** outside the primary slice along the z-position axis remains relatively unchanged.

FIG. **4** depicts the effects upon transverse **100** and longitudinal **102** magnetization from a spectral-spatial pulse having an excitation frequency shifted 100 Hz apart from that of FIG. **3**. Again, primary transverse magnetization **104** is centered along a slice at 0 mm on the z-position axis. In the spectral frequency axis, transverse magnetization **104** is periodic by 1/Δ Hz. Transverse magnetization at 0 Hz, −200 Hz, and 200 Hz is nearly unaffected and magnetization **106** outside the primary slice is relatively small. Primary longitudinal magnetization reduction **108** is also centered at 0 mm on the z-position axis, and is periodic by 1/Δ Hz. Longitudinal magnetization **110** outside the slice and between the peaks of primary magnetization **108** is nearly unaffected in comparison to primary longitudinal magnetization reduction **108**. In other words, the frequency profile of the spectral-spatial pulse creating transverse magnetization **100** and longitudinal magnetization **102** was designed to complement the frequency profile of the pulse of FIG. **3**.

In this regard, FIG. **5** shows the effects upon transverse **112** and longitudinal **114** magnetization of sequentially applying the spectral-spatial pulses of FIGS. **3** and **4**. That is, transverse magnetization **116** is created by a spectral-spatial pulse of a first excitation frequency (such as that of FIG. **3**) and transverse magnetization **118** is created by a second spectral-spatial pulse of a second excitation frequency (such as that of FIG. **4**). Transverse magnetization **120** outside the primary slice and at frequencies falling outside the period of magnetization **116**, **118** (such as at −150 Hz, −50 Hz, 50 Hz, 150 Hz) is relatively small in comparison. Similarly, longitudinal magnetization is decreased **122** by the same spectral-spatial pulse of the first frequency and is decreased **124** by the spectral-spatial pulse of the second frequency. Longitudinal magnetization **122** outside the primary slice, and at frequencies falling outside the periods of magnetization reductions **122**, **124** (such as at −150 Hz, −50 Hz, 50 Hz, 150 Hz) is nearly unaffected.

Referring now to FIG. **6**, a data acquisition sequence **128** incorporating two spectral-spatial pulses **130**, **132** is shown. From beginning to end, sequence **128** may be designed to take less than one second to acquire data. In a preferred embodiment, sequence **128** is adapted for imaging a metabolic process. In this regard, the excitation frequencies of the spectral spatial pulses **130**, **132** may be keyed to the resonant frequencies of a hyperpolarized contrast agent and a metabolite, two contrast agents, two metabolites, and/or combinations thereof. For example, the excitation frequency of spectral spatial pulse **130** may be designed to excite the nuclei of hyperpolarized 13-C labeled pyruvate and the spectral spatial pulse **132** may be designed to excite the nuclei of 13-C alanine, bicarbonate, or lactate (metabolites of 13-C pyruvate). However, it is recognized that other substances with other excitable nuclei are equally applicable (such as 13-C urea or substances having 14-N, 31-P, 19-F, and 23-Na nuclei, other NMR relevant nuclei, and metabolites thereof).

Acquisition sequence **128** begins with emission of a first spectral-spatial pulse **130**, which causes excitation of a substance of corresponding resonant frequency. A dephasing gradient pulse **134** is then applied to dephase the signals/excitations resulting from the first spectral-spatial pulse. A second spectral-spatial pulse **132** is then transmitted, to excite a second substance having a resonant frequency corresponding thereto. Preferably, spectral-spatial pulses **130**, **132** have flip angles of approximately 90 degrees. At this point, longitudinal magnetization and transverse magnetization will appear somewhat like that shown in FIG. **5**. Sequence **128** next includes an RF pulse **136** (which may be slice selective or non-selective) at a frequency range covering the excitation frequencies of both the first **130** and second **132** spectral-spatial pulses. RF pulse **136** preferably has a flip angle of 180 degrees. The read-out or data sampling/acquisition stage begins thereafter, in a reverse order. That is, the signals resulting from the second spectral-spatial pulse **132** are sampled or otherwise acquired first **138**. Read-out may take the form of several well-known acquisition sequences, such as an echo planar imaging (EPI) readout (for example, spin echo EPI), a rapid acquisition with relaxation enhancement (RARE) readout, a true fast imaging with steady precession (trueFISP) readout, or variations thereof. After the readout **138** of spectral-spatial pulse **132**, a rephasing gradient **140** is applied to counteract the effect of the dephasing gradient **134**. Data acquisition then takes place **142** for the signals resulting from spectral-spatial pulse **130** in a well-known manner. Additionally, each readout **138**, **142** may have a timing different from the spectral-spatial pulses or from other read-outs. It is recognized that sequence **128** may be extended to image more than two substances, agents, and/or metabolites. In such embodiments, a dephasing gradient is applied between each spectral-spatial pulse and read-out takes place in an order reversed from the order in which the spectral-spatial pulses were applied, and a rephasing gradient is applied between read-outs.

FIG. **7** is a flowchart illustrating a technique **143** for selective imaging of metabolites in accordance with an embodiment of the present invention. A hyperpolarized contrast agent is introduced into an imaging subject at block **144**. Next, a first spectral-spatial pulse is transmitted at the resonant frequency of the contrast agent at block **146**. This pulse may be delayed a specific time period after introduction of the agent to allow for perfusion into tissues, or for the agent to reach an organ of diagnostic interest. Alternatively, a period of delay may correspond to an amount of time for the contrast agent to be metabolized, in which case the first spectral-spatial pulse may be keyed to the resonance of the metabolite. After the first spectral-spatial pulse has been transmitted by the RF coil assembly, a dephasing gradient pulse is applied at block **148** to dephase the signals/magnetization produced by the spectral-spatial pulse. A second spectral spatial pulse is then transmitted to excite the resonant frequency of a metabolite at block **150**. This may be the first metabolite of a contrast agent to be excited, or may be in addition to another metabolite already excited by the first spectral-spatial pulse. As mentioned above, a number of subsequent dephasing gradient

pulses and spectral spatial pulses may be transmitted and applied to excite additional metabolites or other substances of interest. Once excitations are complete, at block **152** a 180 degree RF pulse is transmitted at a frequency range of sufficient breadth to encompass the resonant frequencies of all the transmitted spectral-spatial pulses.

Signal read-out then begins in a reverse order at block **154**. As shown, the first set of MR signals to be acquired are those produced by the second spectral-spatial pulse **154**. If more than two spectral-spatial pulses were transmitted, the signals of the last spectral-spatial pulse transmitted will be read first. A rephasing gradient pulse is applied at block **156** before the next read-out, to counteract the effects of dephasing gradient pulse applied at block **148**. The read-out for the MR signals produced by the first spectral-spatial pulse is then commenced at block **158**. Once all MR data has been acquired, the data is processed to reconstruct an image, according to any of the known reconstruction techniques at block **160**.

Since data acquisition of technique **143** may take place with just one RF pulse per resonant frequency, and since each spectral-spatial RF pulse is precise enough not to affect nearby resonant frequencies, the full magnetization of hyperpolarized agents may efficiently be utilized. In other words, magnetization created by one spectral-spatial pulse is not destroyed by a subsequent pulse, nor is hyperpolarization used up. In addition, since acquisition sequences of the present invention may be designed to take place in relatively short amounts of time (such as under 1 second), the hyperpolarization of contrast agents and metabolites will typically not decay to a significant degree.

Accordingly, an embodiment of the present invention includes an MR system having a plurality of gradient coils, an RF coil assembly, and a system control. The system control is programmed to cause the RF coil assembly to emit two spectral-spatial RF pulses, then to detect the resulting MR signals from the second pulse before detecting the MR signals from the first pulse.

Another embodiment of the present invention includes a method for MR imaging. The method includes individually exciting the resonant frequencies of two or more metabolites at one flip angle, then simultaneously exciting the resonant frequencies of the metabolites at a second flip angle. After excitation, the resulting MR signals of the metabolites are detected.

In another embodiment of the present invention, a sequence of instructions is stored on a computer readable storage medium. When the instructions are executed by a computer, the computer is caused to request a spectral-spatial pulse at one frequency, a dephasing gradient pulse for that frequency, another spectral-spatial pulse at another frequency, and then an RF pulse over a frequency range including both frequencies

The present invention has been described in terms of the preferred embodiment, and it is recognized that equivalents, alternatives, and modifications, aside from those expressly stated, are possible and within the scope of the appending claims. The order and sequence of process or method steps may be varied or re-sequenced according to alternative embodiments.

What is claimed is:

1. An MR system comprising:

a plurality of gradient coils positioned about a bore of a magnet;

an RF coil assembly coupled to a pulse generator to emit RF pulse sequences and arranged to receive resulting MR signals from a subject of interest; and

a system control coupled to the plurality of gradient coils and the RF coil assembly, the system control programmed to cause the RF coil assembly to:

emit a first spectral-spatial RF pulse;

emit a second spectral-spatial RF pulse after emission of the first spectral-spatial RF pulse; and

detect MR signals resulting from the second spectral-spatial RF pulse before detecting MR signals resulting from the first spectral-spatial RF pulse.

2. The MR system of claim **1** wherein the system control is further programmed to cause a dephasing gradient to be applied between emission of the first spectral-spatial RF pulse and emission of the second spectral-spatial RF pulse.

3. The MR system of claim **2** wherein the system control is further programmed to cause a rephasing gradient pulse to be applied between detection of the MR signals resulting from the second spectral-spatial RF pulse and detection of the MR signals resulting from the first spectral-spatial RF pulse.

4. The MR system of claim **1** wherein the first spectral-spatial RF pulse is designed to excite a first metabolite and the second spectral-spatial RF pulse is designed to excite a second metabolite.

5. The MR system of claim **1** wherein the system control is further programmed to cause emission of more than two spectral-spatial RF pulses.

6. The MR system of claim **5** wherein the system control is further programmed to cause acquisition of MR signals resulting from the emission of the more than two spectral-spatial RF pulses in an order reversed from an order in which the more than two spectral-spatial RF pulses were emitted.

7. The MR system of claim **1** wherein the system control is further programmed to use at least one of an EPI, a RARE, or a trueFISP read-out to detect the MR signals.

* * * * *