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MICROSCOPIC NMR IMAGING

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ABSTRACT

A commercial 60MHz nuclear magnetic resonance spectrometer has been modified to perform non-invasive, high resolution, two dimensional proton density imaging on samples smaller than 10mm.

Orthogonal magnetic field gradients are applied during the experiment to impart a spatial tag to the nuclear spins. The resultant nuclear signal detected by the spectrometer corresponds to a sampling of Fourier space. The exact trajectory in this space depends on the magnitude and timing of the applied gradients. The technique used in this work samples k space in a radial fashion and is termed filtered back projection. Image reconstruction is implemented on a 16 bit personal computer using a two dimensional fast Fourier transform algorithm.

Due to the small volume elements employed the available signal to noise ratio limits the resolution attainable. It is therefore important that the S/N be maximized within the system. To this end careful attention has been paid to the transfer of the nuclear signal from sample to spectrometer. Signal averaging is also used to improve the S/N although this does result in long imaging times (typically 30 to 60 minutes). At present a resolution of about 30 μ m is achievable for a slice thickness of 1.5mm and a S/N of 40. At the time of initial publication in June 1986, this corresponded to a voxel resolution an order of magnitude better than that obtained by other workers in this field.

The orthogonal field gradients used are capable of generating gradients of up to 2Tm⁻¹. This provides the possibility of measuring self diffusion coefficients in an intact sample, using the pulsed field gradient spin echo technique - something which would be difficult to achieve with a large scale imaging system. This thesis reports the first measurements of localised self-diffusion coefficients using a combination of the PFGSE technique and NMR imaging.

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TABLE OF CONTENTS

							page
Title page	i
Abstract	ii
Acknowledgements	iii
Table of contents	iv
List of figures	...	...	...	...	...	...	vii
List of tables	...	...	...	...	...	...	xii
Symbol table	...	...	...	...	...	...	xiii
<u>CHAPTER 1</u>							1
1.1	Introduction	...	...	...	...	...	1
1.2	Organisation of thesis	...	...	...	...	...	2
<u>CHAPTER 2</u>	<u>NMR theory</u>	...	...	...	...	...	3
2.1	Introduction	...	...	...	...	...	3
2.2	The precession equations	...	...	...	...	...	3
2.3	Relaxation processes	...	...	...	...	...	10
2.4	Spin echoes	...	...	...	...	...	12
<u>CHAPTER 3</u>	<u>Imaging theory</u>	...	...	...	...	...	16
3.1	Introduction	...	...	...	...	...	16
3.2	Selective excitation	...	...	...	...	...	20
<u>CHAPTER 4</u>	<u>Imaging techniques</u>	...	...	...	...	...	31
4.1	Fourier zeugmatography	...	...	...	...	...	31
4.2	Filtered back projection	...	...	...	...	...	33
<u>CHAPTER 5</u>	<u>The signal to noise ratio in NMR</u>	...	...	...	...	...	38
<u>CHAPTER 6</u>	<u>Signal to noise and resolution in imaging</u>	...	...	...	...	...	45
6.1	Introduction	...	...	...	...	...	45

6.2	Signal level calculation in Fourler zeugmatography	...	45
6.3	Calculation of the noise level in Fourler zeugmatography	...	47
6.4	Resolution in Fourler zeugmatography	...	60
6.5	Signal level calculation in filtered back projection	...	63
6.6	Calculation of the noise level in filtered back projection	...	70
6.7	Resolution in filtered back projection	...	73
6.8	Comparison of FZ and FBP	...	76
6.9	Ways in which the spatial resolution might be improved	...	76
CHAPTER 7	<u>The FX60 spectrometer</u>	...	79
7.1	Rf probe	...	79
7.2	Lock system	...	81
7.3	Duplexor	...	81
7.4	60MHz receiver	...	85
7.5	T.I. 980A computer	...	85
CHAPTER 8	<u>Imaging hardware</u>	...	88
8.1	Rf probe	...	88
8.2	The radio frequency preamplifier	...	91
8.3	Rf modulation	...	97
8.4	Single sideband modulation	...	105
8.5	Rf transmitter response	...	105
8.6	The imaging gradients, an introduction	...	110
8.7	X and Z gradient coil design	...	111
8.8	Y gradient coil design	...	122
8.9	Controller for the imaging gradients	...	136
8.10	Gradient pulse response times	...	138
8.11	Pulse sequencer	...	139
8.12	Quadrature detection	...	146
8.13	Rf signal switching	...	150
8.14	The graphics computer	...	156
CHAPTER 9	<u>Imaging experiments</u>	...	158
9.1	Proton density Imaging	...	158
9.2	Diffusion contrast Imaging	...	172
9.3	Restricted diffusion	...	183
9.4	Relaxation contrast imaging	...	183

<u>CHAPTER 10</u>	<u>Proposed imaging experiments</u>	...	...	...	188
10.1	Flow imaging	...	...	...	188
10.2	Chemical shift imaging	...	...	...	189
10.3	Imaging of the self correlation function $P_S(r, r_0)$	...	...	...	193
<u>CHAPTER 11</u>	<u>Summary and conclusions</u>	...	...	...	195
<u>APPENDIX A</u>	<u>A Runge-Kutta algorithm for solving the Bloch equations</u>	...	...	...	196
<u>APPENDIX B</u>	<u>The fast Fourier transform</u>	...	...	...	203
<u>APPENDIX C</u>	<u>Derivation of equation 6.44</u>	...	...	...	212
<u>APPENDIX D</u>	<u>Sensitivity enhancement using multiple spin echo summation</u>	...	...	...	213
<u>APPENDIX E</u>	<u>Impedance matching</u>	...	...	...	216
<u>APPENDIX F</u>	<u>A description of the interface and pulse sequencer hardware</u>	...	...	...	221
F.1	TI-980A interface	...	...	...	221
F.2	The pulse sequencer	...	...	...	225
F.3	Graphics computer interface	...	...	...	237
<u>APPENDIX G</u>	<u>Derivation of the attenuation coefficient $R(G, \delta, \Delta)$</u>	...	...	...	240
<u>APPENDIX H</u>	<u>THE TI-980A mnemonic list</u>	...	...	...	244
<u>APPENDIX I</u>	<u>Published work</u>	...	...	...	245
<u>BIBLIOGRAPHY</u>	...	...	...	...	246

LIST OF FIGURES

Figure	Page
2.1 Components of the angular momentum vector \mathbf{I} for a spin 1/2 particle in a magnetic field \mathbf{B}_0	4
2.2 Precession of the nuclear moments about the z axis due to the applied field \mathbf{B}_0	4
2.3 Macroscopic magnetization due to randomly distributed magnetic moments and a population difference between the $m = \pm 1/2$ state.	7
2.4 Motion of the magnetization vector \mathbf{M} in the lab frame during the application of an rf field of frequency $\omega = \gamma B_0$	7
2.5 Precession of the magnetization vector \mathbf{M} about the rf field in the frame of reference rotating clockwise about \mathbf{B}_0 at $\omega_0 = \gamma B_0$	9
2.6 Magnetic fields in the frame of reference rotating about \mathbf{B}_0 at some angular frequency ω	9
2.7 Orientation of the solenoidal coil used to supply the rf pulse and detect the nuclear precession.	11
2.8 Response to the magnetization vector to a $[90^\circ|_x - \tau - 180^\circ|_x]$ pulse sequence.	13
2.9 Response to the magnetization vector to a $[90^\circ|_x - \tau - 180^\circ|_y]$ pulse sequence.	14
2.10 Spin echo formation.	15
3.1 Time and frequency domain signals in NMR.	17
3.2 Effect of adding a gradient to the main magnetic field.	18
3.3 Spin density profile as a function of object orientation.	18
3.4 Selective excitation of a slice of spins.	21
3.5 Rf pulse in the time and frequency domains.	22
3.6 Magnetic fields applied during a selective pulse in a frame of reference rotating clockwise about \mathbf{B}_0 at ω_0	24
3.7 Situation in the frame of reference where $B_{z''} = 0$	24
3.8 Pulse sequence used to selectively excite a slice of spins along the y axis.	26
3.9 An alternative rephasing method used when G_y must remain positive.	26
3.10 Transverse magnetization at time 2τ as a function of position due to selective excitation with a rectangular rf pulse.	27
3.11 Transverse magnetization at time 2τ as a function of position due to selective excitation with sinc modulated rf pulse.	28

3.12	Response to a lms selective rf pulse using sinc and rectangular modulation.	30
4.1	k space sampling for $t_H = 0$	32
4.2	k space sampling for $t_H \neq 0$	32
4.3	Pulse sequence for Fourier Zeugmatography.	34
4.4	Sampling the first quadrant of k space.	34
4.5	Pulse sequence for filtered back projection.	35
4.6	Sampling the first quadrant of k space.	35
5.1	Rf coil dimensions.	39
6.1	Imaging coordinate system.	46
6.2	Diagram showing the 2-D F.T. process used in F.Z.	48
6.3	Non-ideal filter function in k space and image space.	51
6.4	Ideal filter function in k space and image space.	53
6.5	Smoothing factor vs. applied broadening for F.Z.	55
6.6	Image profile at the limit of resolution.	56
6.7	Procedure used to determine the contrast ratio.	57
6.8	Pixel contrast as a function of filter constant for $N = 128$	58
6.9	Signal to noise enhancement as a function p_2	59
6.10	Resolution enhancement in F.Z.	61
6.11	Image reconstruction in FBP.	64
6.12	Projection profile for a cylinder.	65
6.13	Signal processing in filtered back projection.	68
6.14	Smoothing factor vs. applied broadening for FBP.	72
6.15	Pixel contrast as a function of filter constant for filtered back projection with $N=256$	74
6.16	Carr-Purcell pulse sequence used to enhance the sensitivity of the FBP imaging experiment.	78
7.1	Block diagram of the FX-60 spectrometer.	80
7.2a	Block diagram of the lock system.	82
7.2b	Lock modulation.	82
7.3a	The ideal duplexer.	83
7.3b	A practical duplexer.	83
7.4	Schematic of JEOL duplexer.	84
7.5	FX-60 receiver and data acquisition block diagram.	86
8.1	Block diagram of the imaging system.	89
8.2	The modified ^{13}C probe used to perform imaging experiments.	90

8.3	Rf coils used in this work.	90
8.4	Schematic of the rf probe and duplexor used in the imaging system.	92
8.5	Schematic of the rf bridge.	93
8.6	Schematic of the rf preamplifier.	96
8.7	Modulation techniques.	98
8.8	The rf modulator and associated components.	100
8.9	The MC1496P balanced modulator.	102
8.10	Schematic of the rf modulator.	104
8.11	Block diagram of a single sideband rf modulator.	106
8.12	Pulse sequence used to calibrate the modulator.	106
8.13	Tip angle θ as a function of applied DAC input.	108
8.14	Output waveform from the rf modulator required for selective excitation.	109
8.15	Output waveform from the rf transmitter due to the application of the waveform in Fig. 8.14.	109
8.16	A plan view of the G_x and G_z quadrupolar coils showing the distribution of turns and current direction.	112
8.17	Photograph of the quadrupolar imaging coil used to generate the G_x and G_z gradients.	113
8.18	Geometry for finding the field at point (x_1, y_1, z_1) due to current i flowing parallel to the y axis in wire i	114
8.19a	Return path approximation used in this analysis.	117
8.19b	Plan view of the z gradient coil return paths.	117
8.19c	Geometry for finding the field at the point (x_1, y_1, z_1) due to current I flowing parallel to the x axis in wire j	117
8.20	Rotation of the x gradient coil required to simplify the calculation of B_z	119
8.21	y gradient shim coil, configuration and dimensions.	123
8.22a	Percentage variation in the z gradient for the 7/10/7 coil at $y=0\text{mm}$	126
8.22b	Percentage variation in the z gradient for the 7/10/7 coil at $y=3\text{mm}$	127
8.22c	Percentage variation in the z gradient for the 7/10/7 coil at $y=6\text{mm}$	128
8.23a	Percentage variation in the x gradient for the 7/10/7 coil at $y=0\text{mm}$	129
8.23b	Percentage variation in the x gradient for the 7/10/7 coil at $y=3\text{mm}$	130
8.23c	Percentage variation in the x gradient for the 7/10/7 coil at $y=6\text{mm}$	131
8.24a	Percentage variation in the y gradient for the planar shim coil at $y=0\text{mm}$	132
8.24b	Percentage variation in the y gradient for the planar shim coil at $z=0\text{mm}$	133
8.24c	Percentage variation in the y gradient for the planar shim coil at $y=0\text{mm}$ using optimized coil dimensions.	134
8.25	Effective image currents produced within the main magnet pole pieces by the z gradient coil.	135
8.26	Percentage variation in the z field gradient for the 7/10/7 coil at $y=0\text{mm}$ when image gradients are considered.	135
8.27	Power supply and switching unit for the imaging gradients.	137

8.28	Block diagram of the pulse sequencer.	141
8.29	Timing diagram for a 1-D imaging experiment.	144
8.30	Components of the magnetization vector in the lab frame.	147
8.31a	Block diagram of the 4 phase generator.	149
8.31b	Schematic of the quadrature switch.	149
8.32	Projection profile of a tube of water showing the large spike at zero frequency caused by ac coupling within the spectrometer.	151
8.33	Pulse sequences used to observe the zero frequency glitch.	151
8.34	Rf signal switch.	152
8.35	Pulse sequence incorporating the rf signal switch.	154
8.36	Improved projection profile obtained when rf signal switching is used.	154
8.37	Zero frequency glitch returns when exponential filtering is applied.	155
8.38	Improved result obtained by modifying the baseline correction routine.	155
8.39	Monochrome image of a section through an Aralia stem.	157
8.40	A horizontal amplitude profile taken through the "10 tubes image", figure 9.13).	157
9.1	FBP pulse sequence for proton density imaging with slice selection.	159
9.2	Light micrograph of a section through an hydrangea stem.	161
9.3	NMR image of a section through an hydrangea stem.	161
9.4	Light micrograph of a section through a parsnip stem.	163
9.5	NMR image of a section through a parsnip stem.	163
9.6	Light micrograph of a section through a rye grass stem.	165
9.7	NMR image of a section through a rye grass stem.	165
9.8	NMR image of a water filled 10mm tube.	167
9.9	NMR image of a section through a wheat grain.	167
9.10	Anatomical details of the wheat grain.	167
9.11	NMR image of a section through an aralia stem.	169
9.12	NMR image of two concentric tubes filled with water.	169
9.13	NMR image of 10 capillary tubes filled with water.	169
9.14	Light micrograph of a section through the stem of Alyssum Tenium.	171
9.15.	NMR image of a section through the stem of Alyssum Tenium.	171
9.16	Pulse sequence for measuring self diffusion.	174
9.17a	Echo attenuation plot used to calibrate the G_x gradient coil.	175
9.17b	Echo attenuation plot used to calibrate the G_z gradient coil.	176
9.18a	Pulse sequence used to perform diffusion contrast imaging.	177
9.18b	Diffusion contrast imaging with slice selection.	177
9.19	The NMR image of a transverse section through a wheat grain illustrating the influence of the pulsed gradient sequence given in Fig. 9.18a.	178
9.20	Dot matrix image of Fig. 9.19 indicating the location of those features which have been examined to determine the local diffusion coefficients.	179

9.21	Spin echo attenuation plots for regions 3, 4 and 5 of Fig. 9.20.	180
9.22	Wheat grain mount for diffusion contrast experiments.	181
9.23	A series of images showing the effects of restricted diffusion in the parsnip stem.	184
9.24	Images showing T_2 relaxation contrast.	186
9.25	T_1 contrast imaging pulse sequence.	187
10.1	Fluid flow velocity measurement using the PGSE technique.	190
10.2	4-D chemical shift imaging pulse sequence.	192
10.3	Selective saturation chemical shift imaging pulse sequence.	194
A.1	The simulated response to a 90° rf pulse obtained as a result of running the program in table A.1.	202
A.2	The simulated response of 500 spins to a $[90^\circ|_x - \tau - 180^\circ|_y]$ pulse sequence.	202
B.1	"Butterfly diagram" showing the sequence of events which occur in the Radix 2 FFT for $N = 8$	209
E.1	Impedance matching - equivalent circuits.	217
E.2	Alternate impedance matching circuit.	220
F.1	TI-980A interface schematic.	222
F.2	TI-980A interface timing diagram.	224
F.3	Buffer board schematic.	226
F.4	Pulse sequencer schematic - input and memory circuits.	227
F.5	Pulse sequencer schematic - data output and control registers.	228
F.6	Pulse sequencer schematic - memory address counters.	229
F.7	Pulse sequencer schematic - analogue output circuit.	230
F.8	Pulse sequencer schematic - clock and data distributor.	231
F.9	Pulse sequencer schematic - timing unit.	232
F.10	Pulse sequencer schematic - TTL output registers and selection logic.	233
F.11	Timing diagram for the pulse sequencer.	236
F.12	Printed circuit board interconnections.	238
F.13	Centronics buffer port schematic.	239
G.1	Motion of the magnetization vector due to a localized group of spins when the pulse sequence in figure 9.16 is applied.	241

LIST OF TABLES

Table		Page
6.1	Resolution as a function of T_2 for various imaging configurations in FZ.	62
6.2	Resolution as a function of T_2 for various imaging configurations in FBP.	75
8.1	Rf coil characteristics.	88
8.2	Noise figure of the spectrometer as a function of rf gain.	94
8.3	Noise figure as a function of rf gain setting.	95
8.4	Noise figure of the spectrometer and preamp as a function of rf gain.	97
8.5	Tip angle as a function of modulator input.	107
8.6	Calculated gradients.	125
8.7	Gradient coil inductance and resistance.	138
8.8	Pulse sequencer register functions.	140
8.9	Pulse sequencer outputs.	142
8.10	Pulse sequencer code.	143
9.1	Imaging parameters.	160
9.2	Localised water diffusion within the wheat grain.	182
A.1	Program to simulate the response of a group of spins to a 90° , $20\mu\text{s}$, rf pulse.	198
A.2	Program to determine the y magnetization vector, as a function of position following a sinc modulated, selective rf pulse.	199
A.3	Program to simulate the formation of a spin echo.	200
D.1	S/N enhancement and optimum echo number as a function of τ/T_2 .	215
F.1	Pinouts for the TI-980A interface card.	221
F.2	Parallel data transfer routine.	225

SYMBOL TABLE

Symbol	Page
A	Cross sectional area of rf coil. 41
B_0	Main magnetic field, directed along the z axis. 3
B_1	Magnetic field due to applied rf. 6
C	Spatial resolution contrast ratio. 54
dV	Volume element. 16
F	Fourier transform operator. 19
F	Noise factor of spectrometer. 41
F(n)	Filter function. 49
f_r	Frequency corresponding to the edge of a cylinder of radius r. 63
G	Magnetic gradient vector. 16
h	Planck's constant/ 2π 3
I	Angular momentum vector. 3
I	Spin quantum number. 3
I	Coil current. 40
Im[]	Imaginary part of complex term in brackets. 49
j	$(-1)^{1/2}$ 16
k	Reciprocal space position vector. 16
k_B	Boltzmann's constant. 38
L	Length of conductor used in rf coil. 42
L	Inductance of rf coil. 41
l	Length of rf coil. 38
M	Magnetization vector. 6
m	Representation of r in the computer. 45
m	Spin magnetic quantum number. 6
m_r	Number of data points representing the radius of a cylinder. 47
n	Representation of k in the computer. 45
n_b	Number of points characterising the decay of the filter function. 50
N	Number of data points in fid. 33
N_{acc}	Number of time domain accumulations. 33
N_h	Number of hydrogen nuclei per unit volume. 6
N_k	Noise level in k space. 49
N_p	Number of projection used in FBP. 37
N_r	Noise level in image space. 49
N_t	Number of turns on coil. 38
P	Principle part. 67

P_{\pm}	Probability that the nuclear spin will be aligned (-) with or opposed (+) to B_0 .	38
p	Wire circumference.	42
p_2	$= T_2 \Delta f$	54
Q	Quality factor of rf coil.	41
Re[]	Real part of complex term in brackets.	25
R	Rf coil radius	38
\mathbf{r}	Image space position vector.	16
r_c	Rf coil resistance.	41
r	Rf coil wire radius.	38
$\mathbf{S}(\text{FBP})$	Smoothing function used in FBP.	71
$\mathbf{S}(\text{FZ})$	Smoothing function used in FZ.	52
S_k	Spatial frequency domain data.	45
S_r	Image domain data.	45
T	Total sampling time.	45
T_1	Spin-lattice relaxation time.	10
T_2	Spin-spin relaxation time.	10
T_2^*	Transverse relaxation time.	12
T_c	Coil temperature in Kelvin.	41
T_r	Experiment repetition time.	76
T_s	Sample temperature in Kelvin.	38
V_c	Volume of coil.	42
V_s	Volume of sample.	38
V_c	Carrier level.	99
V_m	Modulation level.	99
γ	Gyromagnetic ratio.	3
Δf	Frequency domain bandwidth of spectrometer.	41
Δy	Slice thickness.	46
Δz	Spatial resolution in the final image.	38
$\Delta \omega$	Offset from resonance.	146
δ	Skin depth.	42
θ	Tip angle.	9
$\boldsymbol{\mu}$	Magnetic moment vector.	3
μ_0	Permeability of free space.	40
μ_r	Relative permeability.	42
ξ	Induced EMF amplitude.	10
ρ	Proton density function.	16
ρ	Coil wire resistivity.	42

σ	Coil proximity factor.	...	...	...	...	...	42
τ	Torque.	...	...	...	...	...	3
τ	Short time interval.	...	...	...	...	...	12
τ_c	Molecular correlation time.	...	...	...	...	...	10
ϕ	Projection angle.	...	...	...	...	...	35
Ψ	Filtered profile.	...	...	...	...	...	36
ω_0	Larmor precession frequency due to B_0.	...	...	...	...	...	5
ω_1	Larmor precession frequency due to B_1.	...	...	...	...	...	8