

Contents

1	Introduction	1
1.1	Quantum computing	1
1.1.1	Methods	3
1.2	Ion trap quantum computers	3
1.3	Thesis outline	6
2	Theory	9
2.1	Ion traps	9
2.1.1	Mathieu Equation	10
2.1.2	Recent ion trap developments	13
2.2	Ytterbium	14
2.2.1	Photoionization	14
2.2.2	Ionic schemes	15
2.2.3	Preparation method calculations	18
2.2.4	935 nm system calculations	21
2.3	Laser cooling	24
2.3.1	Doppler cooling	24
2.3.2	Sideband cooling	27
2.4	Qubit dynamics	29
2.5	Gradient scheme	32
2.5.1	Pros and cons of the Gradient scheme	36
2.6	Pulses	37
2.6.1	Optimal control theory (OCT) pulses	38

2.6.2	Composite pulses	40
2.6.3	Pulse simulations	41
2.7	Decoherence	43
2.7.1	Decoherence Free subspace (DFS)	44
2.8	Alternative gradient scheme	45
2.8.1	Dressed state picture	46
2.8.2	From noisy to stable transitions	52
2.8.3	Two level system dressed state based scheme	54
2.8.4	Possible dressed state based $^{171}\text{Yb}^+$ qubits	56
3	Experimental Description	61
3.1	Trap description	61
3.2	Optical set up	64
3.2.1	Solid state system: 369 nm	64
3.2.2	Diode laser system: 935 nm, 638 nm, 399 nm	67
3.2.3	λ -meter	68
3.3	Non optical fields.	69
3.3.1	Microwave	69
3.3.2	Radio frequency fields.	72
3.3.3	Static fields.	74
3.4	Detection	75
3.5	Experimental control	76
3.6	Data evaluation	80
3.6.1	Poissonian statistics	80
3.6.2	Time resolved detection	83
4	Pulse Measurements	87
4.1	Measuring pulse fidelities	87
4.1.1	Measuring pulse fidelities: what was measured	87
4.1.2	Measuring pulse fidelities: how to measure it	89

4.2	Optimal Control Theory based pulses	91
4.3	Composite pulses	94
4.4	Summary	97
5	Bare State Measurements	99
5.1	Preparation improvement.	99
5.2	935 dependence	102
5.3	Detection efficiency	104
5.4	Measurements of magnetic field sensitive levels	105
5.5	Coherences after a 50 Hz trigger	107
5.6	Summary	111
6	Dressed States	113
6.1	Preparation methods	113
6.1.1	Robustness of STIRAP	117
6.1.2	Adiabatic preparation of a 2-level dressed state system.	124
6.2	Two level operations on dressed states	127
6.3	Three level system	130
6.4	Summary	136
7	Conclusion	137
A	Dipole moment calculation	141
A.1	Coupling constants	141
A.1.1	Electric dipole moments	143
A.1.2	<i>jk</i> coupling	145
A.2	$^{171}\text{Yb}^+$	146
B	Optical Bloch Equations	155
B.1	Many level systems	157
B.1.1	2 level system	157

B.1.2 3 level system	158
B.1.3 8 level system (369 nm)	160
B.1.4 20 level system (369 nm + 935 nm)	162
C Magnetic Field Dependence	165
D Pulse support	167
D.1 Ramsey phase probe result	167
D.2 Quaternion simulations	169
E Circuits	173
E.1 Phase lock loop	173
E.2 50 Hz TTL signal	174
F Program Catalogue	177
F.1 Mfile packages	177
F.1.1 Rabi measurements	178
F.1.2 Ramsey measurements	180
F.1.3 Pulses	181
F.1.4 Simulations	182
F.2 Mathematica files	184
F.3 Vi libraries	185
G Devices	191
G.1 $^{171}\text{Yb}^+$ trap experiment equipment list	191
Bibliography	195
Acknowledgements	203