



## Scalable Control Electronics for a Spin Based Quantum Computer

Lotte Geck

Information  
Band / Volume 65  
ISBN 978-3-95806-540-6

Forschungszentrum Jülich GmbH  
Zentralinstitut für Engineering, Elektronik und Analytik (ZEA)  
Systeme der Elektronik (ZEA-2)

# **Scalable Control Electronics for a Spin Based Quantum Computer**

Lotte Geck

Schriften des Forschungszentrums Jülich  
Reihe Information / Information

Band / Volume 65

---

ISSN 1866-1777

ISBN 978-3-95806-540-6

---

# Contents

---

<b>Abstract</b>	i
<b>List of Figures</b>	vii
<b>List of Tables</b>	xi
<b>Acronyms</b>	xiii
<b>1 Introduction</b>	1
1.1 Problem at hand . . . . .	2
1.2 Approach of this thesis . . . . .	4
1.3 Organization of this work . . . . .	6
<b>2 Basics of Quantum Information and Quantum Computing</b>	7
2.1 The qubit . . . . .	10
2.2 Multiple qubits . . . . .	12
2.3 Quality measures for qubits and gates . . . . .	13
2.3.1 Gate operations . . . . .	13
2.4 Qubit implementations and their scalability potential . . . . .	14
2.4.1 The GaAs S-T <sub>0</sub> qubit . . . . .	16
2.5 State of the Art (scalable) qubit control . . . . .	21
<b>3 Feasibility and scalability of cryogenic control electronics for qubits</b>	23
3.1 Motivation and method . . . . .	23
3.2 Requirements for qubit operation extracted from current lab experiments	25
3.3 Concept for scalable cryogenic control electronic . . . . .	27
3.3.1 Memory . . . . .	29
3.3.2 Managing Unit . . . . .	30
3.3.3 Bias generation . . . . .	31
3.3.4 RF generation . . . . .	36
3.3.5 Feasibility conclusion . . . . .	37
3.4 Area and Power estimations . . . . .	37
3.4.1 DAC area and power . . . . .	41
3.4.2 Control electronics area and power . . . . .	43
3.5 Reduction possibilities of area and power . . . . .	45
3.6 Critical discussion of assumptions . . . . .	48
3.7 Scalability Discussion and Conclusion . . . . .	49

<b>4 Behavioral modeling of electronics</b>	<b>53</b>
4.1 Motivation . . . . .	53
4.2 Simulation with Simulink . . . . .	54
4.3 Top Level Model . . . . .	55
4.4 QC levels at higher temperatures . . . . .	58
4.5 Control electronics . . . . .	62
4.5.1 Managing unit . . . . .	62
4.5.2 Memory . . . . .	69
4.5.3 Bias generation . . . . .	71
4.5.4 RF generation . . . . .	73
4.6 Readout . . . . .	75
4.7 Discussion and implications on scalability . . . . .	75
4.8 Summary . . . . .	77
<b>5 Qubit Modeling and Characterization</b>	<b>79</b>
5.1 Motivation and Method . . . . .	79
5.2 Behavioral modeling of the qubit state . . . . .	80
5.3 Qubit operation . . . . .	82
5.3.1 Finding pulse sequences . . . . .	83
5.4 Sensitivity . . . . .	88
5.4.1 Conclusion . . . . .	92
5.5 Frequency behaviour . . . . .	92
5.5.1 Sinusoidal interference signal . . . . .	92
5.5.2 Filter functions . . . . .	94
5.5.3 Summary . . . . .	96
5.6 Noise power influence . . . . .	96
5.6.1 Summary . . . . .	98
5.7 Conclusions and implication for circuit designer . . . . .	98
<b>6 Modeling qubits and electronics together</b>	<b>101</b>
6.1 Motivation and method . . . . .	101
6.2 Modeled non-idealities . . . . .	101
6.2.1 Jitter . . . . .	102
6.2.2 Noise on the reference voltage . . . . .	103
6.2.3 DAC nonlinearities . . . . .	103
6.3 Combined simulation with exemplary pulses . . . . .	105
6.3.1 Results . . . . .	107
6.4 Conclusion . . . . .	110
<b>7 Summary, Conclusion and Outlook</b>	<b>111</b>
7.1 Summary . . . . .	111
7.2 Conclusion . . . . .	113

7.3   Outlook . . . . .	113
<b>Bibliography</b>	<b>xv</b>
<b>Curriculum Vitae</b>	<b>xxvii</b>
<b>Publications and additional contributions</b>	<b>xxix</b>
<b>A   Estimations block diagrams</b>	<b>xxxi</b>

Information  
Band / Volume 65  
ISBN 978-3-95806-540-6