



# Integrated Control Electronics for Qubits at Ultra Low Temperature

Dennis Nielinger

Information

Band / Volume 80

ISBN 978-3-95806-631-1

---

# Contents

---

<b>Acknowledgement</b>	<b>iii</b>
<b>List of Figures</b>	<b>xi</b>
<b>List of Tables</b>	<b>xv</b>
<b>Acronyms</b>	<b>xvii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	1
1.2 Organization of this thesis . . . . .	2
<b>2 Fundamentals of Quantum Computing</b>	<b>3</b>
2.1 Requirements for Quantum Computing . . . . .	3
2.2 Quantum Mechanics . . . . .	4
2.3 What is a qubit? . . . . .	5
2.4 Quantum Gates . . . . .	8
2.5 Qubit Implementations . . . . .	10
2.5.1 Superconducting Qubits . . . . .	10
2.5.2 Trapped Ions . . . . .	11
2.5.3 Quantum Dots . . . . .	12
2.5.4 Quantum Annealing . . . . .	16
2.5.5 Comparison . . . . .	17
<b>3 Electronic Control of Qubits</b>	<b>19</b>
3.1 GaAs Control . . . . .	19
3.2 SiGe Control . . . . .	21
3.3 Partitioning . . . . .	23
3.3.1 State of the Art . . . . .	23
3.3.2 Vision . . . . .	24
3.4 Power Consumption . . . . .	26
3.5 Interface . . . . .	26
3.6 Integrated Cryogenic CMOS . . . . .	27
<b>4 Scalable Quantum Bit Control</b>	<b>33</b>
4.1 Clock Buffer . . . . .	34

4.2	Oscillators . . . . .	38
4.2.1	Basic Feedback Theory . . . . .	38
4.2.2	Digital Controlled Oscillator . . . . .	39
4.2.3	Voltage Controlled Oscillator . . . . .	43
4.2.4	Output Amplifier . . . . .	47
4.3	Pulse Digital-to-Analog Converter . . . . .	48
4.3.1	R-String . . . . .	49
4.3.2	R-2R . . . . .	50
4.3.3	Sigma-Delta . . . . .	51
4.3.4	Current Steering . . . . .	51
4.3.5	Comparison . . . . .	52
4.3.6	Implementation . . . . .	53
4.4	Toplevel . . . . .	60
4.4.1	Inter-IC Bus . . . . .	60
4.4.2	Power Domains . . . . .	61
<b>5</b>	<b>Measurement Results</b>	<b>65</b>
5.1	Measurement Setup . . . . .	65
5.2	Clock Buffer . . . . .	67
5.3	Discussion of the Clockbuffer Measurement Results . . . . .	71
5.4	Voltage Controlled Oscillator . . . . .	72
5.4.1	Phase Noise . . . . .	76
5.5	Discussion of the VCO Measurement Results . . . . .	77
5.6	Digitally Controlled Oscillator . . . . .	78
5.7	Discussion of the DCO Measurement Results . . . . .	81
5.8	Pulse Digital-to-Analog Converter . . . . .	82
5.9	Discussion of the DAC Measurement Results . . . . .	89
<b>6</b>	<b>Summary, Conclusion and Outlook</b>	<b>91</b>
6.1	Summary . . . . .	91
6.2	Outlook . . . . .	92
6.3	Conclusion . . . . .	93
	<b>Bibliography</b>	<b>xix</b>

Information

Band / Volume 80

ISBN 978-3-95806-631-1

Mitglied der Helmholtz-Gemeinschaft

