

Contents to Volume 2

SQUIDart by Claus Grupen (drawing) *XXII*

Preface *XXIII*

List of Contributors *XXV*

5	Power Applications	<i>603</i>
5.1	Superconducting Cables	<i>603</i> <i>Werner Prusseit, Robert Bach, and Joachim Bock</i>
5.1.1	Power Cable Technology	<i>603</i>
5.1.2	Current Rather than Voltage – Advantages of Superconducting Cables	<i>604</i>
5.1.3	HTS-Cable Designs	<i>605</i>
5.1.4	Economic Benefits of HTS Distribution Grids	<i>612</i>

- 5.1.5 Specific Applications for HTS-Cables 613
- 5.1.6 Conclusions 614
- References 614
- 5.2 Practical Design of High-Temperature Superconducting Current Leads 616
Jonathan A. Demko
- 5.2.1 Introduction 616
- 5.2.2 Cryogenic Copper Properties 618
- 5.2.3 Thermally Optimized Current Lead in a Vacuum 619
- 5.2.4 Nonoptimal Operation 622
- 5.2.5 Vapor- or Forced Flow-Cooled Current Leads 623
- 5.2.5.1 Current Lead Heat Exchangers 624
- 5.2.6 Refrigeration Requirements 626
- 5.2.7 Short-Duration Overcurrent Heating 628
- 5.2.7.1 Conclusions 628
- References 629
- 5.3 Fault Current Limiters 631
Swarn Singh Kalsi
- 5.3.1 Introduction 631
- 5.3.2 SFCL Concept Description 632
- 5.3.2.1 Resistive Fault Current Limiters (SFCL) 633
- 5.3.2.1.1 Noninductive (Bifilar) Coils 634
- 5.3.2.1.2 Straight Elements 635
- 5.3.2.1.3 Shielded Iron Core SFCL 635
- 5.3.2.1.4 Saturated Iron Core SFCL 636
- 5.3.3 Challenges 637
- 5.3.3.1 Challenges of Resistive SFCL 637
- 5.3.3.2 Challenges of Inductive SFCL 638
- 5.3.4 Manufacturing Issues 639
- 5.3.5 Examples of Built Hardware 639
- 5.3.5.1 SFCL by AMSC/Siemens/Nexans Team 640
- 5.3.5.2 Other Wire-Based Projects 641
- 5.3.5.3 KEPRI SFCL 641
- 5.3.5.4 InnoPower Saturable Core SFCL 641
- 5.3.6 Overlook 643
- References 643
- 5.4 Transformers 645
Antonio Morandi
- 5.4.1 Introduction 645
- 5.4.2 Basic Aspects 646
- 5.4.2.1 Total Size and Weight 646
- 5.4.2.2 Leakage Inductance 647
- 5.4.2.3 Losses 647
- 5.4.2.4 Fault Current Limitation 648
- 5.4.2.5 Coreless Transformer 648
- 5.4.3 Construction Issues and State of the Art of Superconducting Transformers 649
- 5.4.3.1 Superconducting Materials 649
- 5.4.3.2 Cryostat and Cooling System 650
- 5.4.3.3 SC Conductor 652
- 5.4.3.4 Windings, Insulation, and Bushing 652
- 5.4.4 State-of-the-Art Superconducting Transformers 653
- 5.4.5 Design and Economic Evaluation of a HTS Power Transformer 654
- 5.4.5.1 Design Procedure 654
- 5.4.5.2 Total Owning Cost and Admissible AC Losses of a 40 MVA – 132/15 kV HTS Transformer 657
- References 659
- 5.5 Energy Storage (SMES and Flywheels) 660
Antonio Morandi
- 5.5.1 Introduction 660
- 5.5.2 Parameters of an Energy Storage System 660
- 5.5.3 Applications of Energy Storage 661
- 5.5.4 SMES 664
- 5.5.4.1 Conductor and Coil 666
- 5.5.4.2 Power Conditioning System 667
- 5.5.4.3 State of the Art of SMES 669
- 5.5.5 Flywheels 670
- 5.5.5.1 Superconducting Bearings 671
- 5.5.5.2 State of the Art of Superconducting Flywheels 672
- References 672
- 5.6 Rotating Machines 674
Swarn Singh Kalsi
- 5.6.1 Introduction 674
- 5.6.2 Topology 675
- 5.6.3 Design and Analysis 679
- 5.6.4 Key Components and Manufacturing Issues 683
- 5.6.4.1 Rotor Design Issues 683
- 5.6.4.1.1 HTS Wire Technology 683
- 5.6.4.1.2 HTS Pole Construction 684
- 5.6.4.1.3 Cooling Systems for HTS 686
- 5.6.4.1.4 Rotor Cryostat Configuration 687
- 5.6.4.1.5 Rotary Seal Assembly 688
- 5.6.4.1.6 EM Shield 688
- 5.6.4.1.7 Exciter 690
- 5.6.4.2 Stator Winding 690

- 5.6.5 Outlook 690
References 691
- 5.7 SmartGrids: Motivations, Stakes, and Perspectives/Opportunities for Superconductivity 693
Nouredine Hadjsaid, Pascal Tixador, Jean-Claude Sabonnadiere, Camille Gandioli, and Marie-Cécile Alvarez-Hérault
 - 5.7.1 Introduction 693
 - 5.7.1.1 The New Energy Paradigm 693
 - 5.7.1.2 Integration of Advanced Technologies 696
 - 5.7.2 The European Energy Prospective 698
 - 5.7.3 Main Triggers of the Development of the SmartGrids 701
 - 5.7.4 Definitions of the SmartGrids 702
 - 5.7.5 Objectives Addressed by the Transmission SmartGrids 703
 - 5.7.6 Objectives Addressed by the Distribution SmartGrids 704
 - 5.7.6.1 Development of Distribution Networks: Toward Smarter Grids 704
 - 5.7.6.2 Technical Objectives 705
 - 5.7.6.3 Socioeconomic and Environmental Objectives 705
 - 5.7.7 Examples of Development of Innovative Concepts 705
 - 5.7.8 Scientific, Technological, Economical, and Sociological Challenges 706
 - 5.7.8.1 Scientific and Technological Locks 707
 - 5.7.8.2 Economical and Sociological “Locks” 708
 - 5.7.9 Opportunities for Superconductivity 708
 - 5.7.9.1 Superconducting Fault Current Limiter 709
 - 5.7.9.2 Superconducting Cables 717
 - 5.7.9.3 Superconducting Storage: Superconducting Magnetic Energy Storage (SMES) 718
 - 5.7.10 Conclusion 718
References 719
- 6 Superconductive Passive Devices 723**
 - 6.1 Superconducting Microwave Components 723
Neeraj Khare
 - 6.1.1 Introduction 723
 - 6.1.2 Resonators 724
 - 6.1.3 Filters 725
 - 6.1.3.1 Cryogenic Receiver Front End 728
 - 6.1.4 Antenna 728
 - 6.1.5 Delay lines 730
References 731
 - 6.2 Cavities for Accelerators 734
Sergey A. Belomestnykh and Hasan S. Padamsee
 - 6.2.1 Introduction to Radio Frequency Superconductivity for Accelerators 734
 - 6.2.1.1 Benefits of SRF Cavities for Particle Accelerators, Cavity Types, and Figures of Merit 734
 - 6.2.1.2 General Architecture of an SRF Cryomodule 736
 - 6.2.1.3 Accomplishments of RF Superconductivity for Accelerators 738
 - 6.2.2 Physics of RF Superconductivity 740
 - 6.2.2.1 Surface Impedance of Superconductors 740
 - 6.2.2.2 RF Critical Magnetic Field, H_{sh} the Superheating Critical Field 744
 - 6.2.3 Fabrication and Surface Preparation 744
 - 6.2.3.1 Cavity Fabrication 745
 - 6.2.3.2 Methods of Cavity Surface Preparation 745
 - 6.2.4 Effects Limiting Performance of Superconducting Cavities 748
 - 6.2.4.1 Quench – Breakdown of Superconductivity 748
 - 6.2.4.2 Multipacting 750
 - 6.2.4.3 Field Emission and Processing 752
 - 6.2.4.4 Q Versus E_{acc} : Low-, Medium-, and High-Field Effects 753
 - 6.2.4.5 RF Critical Magnetic Field: Experiments 756
 - 6.2.5 Concluding Remarks 757
Acknowledgments 758
References 758
 - 6.3 Superconducting Pickup Coils 762
Audrius Brazdeikis and Jarek Wosik
 - 6.3.1 Introduction 762
 - 6.3.2 HTS Pickup Coils for High-Field MRI Applications 763
 - 6.3.2.1 Signal-to-Noise Ratio 764
 - 6.3.2.2 SNR Gain 765
 - 6.3.2.3 HTS Coil Design 767
 - 6.3.3 Superconducting Pickup Coils for SQUID Measurements 772
 - 6.3.4 SQUID Pickup for ULF NMR/MRI 773
 - 6.3.4.1 General Pickup Coil Considerations 774
References 776
 - 6.4 Magnetic Shields 780
James R. Claycomb
 - 6.4.1 Introduction 780
 - 6.4.2 Low-Field Magnetic Measurements 780
 - 6.4.3 Image Surface Gradiometers 781
 - 6.4.4 Superconducting Disk 783
 - 6.4.4.5 Semi-Infinite Superconducting Tube 785
 - 6.4.4.5.1 Superconducting Tube in an Axial Noise Field 786
 - 6.4.4.5.2 Superconducting Tube in Transverse Noise Field 787
 - 6.4.6 Semi-Infinite Highly Permeable Tube 788

- 6.4.6.1 Permeable Tube in an Axial Noise Field 788
 - 6.4.6.2 Permeable Tube in Transverse Noise Field 788
 - 6.4.7 Partitioned Superconducting Tubes 789
 - 6.4.7.1 Partitioned Tube in Axial Noise Field 789
 - 6.4.7.2 Partitioned Tube in Transverse Noise Field 791
 - 6.4.8 Numerical Modeling of Superconductors in External Fields 791
 - 6.4.8.1 Simply-Connected Superconductors in Low Fields 791
 - 6.4.8.2 Multiply-Connected Superconductors in Low Fields 793
 - 6.4.8.3 Trapped Flux in Multiply-Connected Superconductors 794
 - 6.4.8.4 Simply-Connected Superconductors in High Fields 795
 - 6.4.8.5 Multiply-Connected Superconductors in High Fields 795
 - 6.4.8.6 Combinations of Superconducting and μ -Metal Shielding 796
 - 6.4.8.7 Screening Current and Inductance Calculations 797
 - 6.4.9 AC-Shielding Applications 798
 - 6.4.9.1 Eddy Current Probes for Nondestructive Testing 799
 - 6.4.9.2 Superconducting Fault Current Limiters 799
 - 6.4.10 Space Applications 801
 - 6.4.11 Commercial HTS Magnetic Shields 803
 - 6.4.12 Conclusion 803
References 804

 - 7 Applications in Quantum Metrology 807**
 - 7.1 Quantum Standards for Voltage 807
Johannes Kohlmann
 - 7.1.1 Introduction 807
 - 7.1.2 Fundamentals 808
 - 7.1.2.1 Measurements, Units, and the SI 808
 - 7.1.2.2 Josephson Effects and Voltage Standards 809
 - 7.1.2.3 From Josephson Effects to Modern JVSs 810
 - 7.1.3 Dc Measurements: Conventional Josephson Voltage Standards 812
 - 7.1.4 From dc to ac Josephson Voltage Standards 813
 - 7.1.4.1 Binary-Divided Arrays 814
 - 7.1.4.1.1 Design of Binary-Divided Arrays 815
 - 7.1.4.1.2 Realization of Binary-Divided Arrays 816
 - 7.1.4.1.3 Applications of Binary-Divided Arrays 818
 - 7.1.4.2 Pulse-Driven Arrays 819
 - 7.1.4.2.1 Design of Pulse-Driven Arrays 819
 - 7.1.4.2.2 Realization of Pulse-Driven Arrays 820
 - 7.1.4.2.3 Applications of Pulse-Driven Arrays 820
 - 7.1.4.3 Conclusions 821
Acknowledgments 821
References 822
- 7.2 Single Cooper Pair Circuits and Quantum Metrology 828
Alexander B. Zorin
 - 7.2.1 Introduction 828
 - 7.2.2 Engineering of the Electromagnetic Environment 829
 - 7.2.3 The Bloch Oscillations and Their Phase Locking 831
 - 7.2.4 New Concept of the Experiment with Superconducting Nanowires 833
 - 7.2.5 Cooper Pair Pumps and Single Quasiparticle Circuits 835
 - 7.2.6 Metrological Aspect 836
 - 7.2.7 Conclusion 839
Acknowledgement 840
References 840
-
- 8 Superconducting Radiation and Particle Detectors 843**
 - 8.1 Radiation and Particle Detectors 843
Claus Grupen
 - 8.1.1 Introduction 843
 - 8.1.2 Basic Interactions 844
 - 8.1.3 Historical Detectors 846
 - 8.1.4 Gaseous Detectors 847
 - 8.1.5 Scintillators and Solid-State Detectors 849
 - 8.1.5.1 Solid-State Detectors 849
 - 8.1.6 Cherenkov Detectors 850
 - 8.1.7 Calorimeters 851
 - 8.1.8 Cryogenic Detectors 851
Acknowledgments 857
References 858
 - 8.2 Superconducting Hot Electron Bolometers and Transition Edge Sensors 860
Giovanni P. Pepe, Roberto Cristiano, and Flavio Gatti
 - 8.2.1 Introduction 860
 - 8.2.2 The Energy Scenario and Timescales 862
 - 8.2.2.1 The Electron–Phonon Time 864
 - 8.2.2.2 The Phonon–Electron Time 864
 - 8.2.3 The Hot Electron Bolometer 864
 - 8.2.4 Transition Edge Sensor 867
 - 8.2.5 The Main Physical Parameters 868
 - 8.2.5.1 Responsivity 868
 - 8.2.5.2 Noise 870
 - 8.2.6 Recent Achievements 873
 - 8.2.6.1 Superconducting Hot Electron Bolometers 873
 - 8.2.6.2 Transition Edge Sensors 876

- 8.2.6.2.1 Low Power Level 876
- 8.2.6.2.2 Linear Response 877
- 8.2.6.2.3 High Energy Resolution 878
- 8.2.6.2.4 Low Threshold and Calorimetry 878
- References 878

- 8.3 SIS Mixers 881
Doris Maier

- 8.3.1 Introduction 881
- 8.3.2 Superconducting Tunnel Junctions 882
 - 8.3.2.1 Quasiparticle Tunneling 882
 - 8.3.2.2 Josephson Effects 883
 - 8.3.2.3 SIS Junctions with Applied Microwave Radiation 884
 - 8.3.2.3.1 Photon-Assisted Tunneling 884
 - 8.3.2.3.2 Shapiro Steps 885
 - 8.3.3 Quantum Mixer Theory 886
 - 8.3.3.1 Large-Signal Problem 886
 - 8.3.3.2 Small-Signal Problem 887
 - 8.3.3.3 Noise Properties 889
 - 8.3.4 SIS Mixers 889
 - 8.3.4.1 Mixer Fabrication 889
 - 8.3.4.2 Mixer Design 890
 - 8.3.4.2.1 Waveguide Probe 891
 - 8.3.4.2.2 Tuning Structure 891
 - 8.3.4.2.3 RF Match 892
 - 8.3.4.2.4 IF Match 892
 - 8.3.4.3 Mixer Block 893
 - 8.3.4.4 Noise Measurements 893
 - 8.3.4.5 Mixer Types 894
 - 8.3.4.5.1 Single-Sideband Mixers 895
 - 8.3.4.5.2 Sideband-Separating Mixers 895
 - 8.3.5 Perspectives 897
 - References 898

- 8.4 Superconducting Photon Detectors 902
Michael Siegel and Dagmar Henrich

- 8.4.1 Superconducting Single-Photon Detectors 902
 - 8.4.1.1 Basics of Operation of a Superconducting Nanowire Single-Photon Detector (SNSPD) 903
 - 8.4.1.2 Hot-Spot and Vortex-Assisted Models 906
 - 8.4.1.2.1 The Hot-Spot Model 906
 - 8.4.1.2.2 Vortex-Assisted Photon Detection Model 908
 - 8.4.1.3 Fabrication and Characterization of SNSPD 910
 - 8.4.1.3.1 Optical Coupling and Characterization of SNSPD 910
 - 8.4.1.3.2 Detection Efficiency 913
 - 8.4.1.3.3 Spectral Detection Efficiency of a Spiral SNSPD 917
 - 8.4.1.4 SNSPD Applications 919
- 8.4.2 Photon and Particle Detectors with Superconductor Tunnel Junctions (STJ) 922
 - 8.4.2.1 Introduction of STJ 922
 - 8.4.2.2 Basics of STJ Operation 923
 - 8.4.2.2.1 Performance 924
 - 8.4.2.2.2 STJ Applications 925
 - 8.4.3 Conclusions 927
 - References 928

- 8.5 Applications at Terahertz Frequency 930
Masayoshi Tonouchi

- 8.5.1 Introduction 930
- 8.5.2 Application of Terahertz Waves 930
- 8.5.3 Superconductive Electronics for Terahertz Application 933
- 8.5.4 Summary 938
- References 939

- 8.6 Detector Readout 940
Thomas Ortlepp

- 8.6.1 Introduction 940
- 8.6.2 Analog Readout 940
- 8.6.3 Resonant Circuit Readout 943
- 8.6.4 Digital Event Readout 944
- References 945

- 9 Superconducting Quantum Interference (SQUIDs) 949**

- 9.1 Introduction 949
Robert L. Fagaly
- References 951

- 9.2 Types of SQUIDs 952
Robert L. Fagaly

- 9.2.1 Introduction 952
- 9.2.2 RF and DC SQUIDs 952
- 9.2.3 Other Modulation Schemes 955
 - 9.2.3.1 External Feedback 955
- 9.2.4 Sensitivity 956
 - 9.2.4.1 Operation in Magnetic Fields 957
- 9.2.5 Other Types of SQUIDs 958
 - 9.2.5.1 The Bi-SQUID 958
 - 9.2.5.2 Superconducting Quantum Interference Filters 958
- 9.2.6 Limitations on SQUID Technology 959

- 9.2.6.1 Differential Measurements 960
- 9.2.6.2 Slew Rate Limitations 960
- 9.2.6.2.1 1/f Noise 960
- 9.2.6.3 HTS Limitations 960
- 9.2.6.4 The Vector Nature of SQUID Magnetometers 961
- 9.2.7 Environmental Noise 961
- 9.2.7.1 Gradiometers 961
- 9.2.7.2 Magnetic Shields and Shielding Rooms 963
- 9.2.8 Cryogenic Requirements 963
- References 965

- 9.3 Magnetic Field Sensing with SQUID Devices 967
- 9.3.1 SQUIDs in Laboratory Applications 967
Robert L. Fagaly
- 9.3.1.1 Introduction 967
- 9.3.1.2 Applications 968
- 9.3.1.3 Laboratory Applications 968
- 9.3.1.3.1 Current Measurements 969
- 9.3.1.3.2 Voltage Measurements 971
- 9.3.1.3.3 Resistance Measurements 971
- 9.3.1.3.4 AC Impedance Measurements 971
- 9.3.1.3.5 Magnetic Susceptibility 972
- 9.3.1.3.6 Variable Temperature SQUID Susceptometers 972
- 9.3.1.3.7 Other SQUID Measurement Techniques 974
- References 975
- 9.3.2 SQUIDs in Nondestructive Evaluation 977
Hans-Joachim Krause, Michael Mück, and Saburo Tanaka
- 9.3.2.1 Introduction 977
- 9.3.2.2 NDE in Static Magnetic Fields 977
- 9.3.2.3 Eddy-Current Testing 982
- 9.3.2.4 Nondestructive Evaluation Using SQUID Microscopes 986
- 9.3.2.5 Conclusion 988
- References 988
- 9.3.3 SQUIDs in Biomagnetism 992
Hannes Nowak
- 9.3.3.1 Biomagnetism 992
- 9.3.3.2 History 993
- 9.3.3.3 Biomagnetic Fields 994
- 9.3.3.4 Gradiometers 995
- 9.3.3.5 Shielding: Magnetically and Electrically Shielded Rooms 997
- 9.3.3.6 Dewar/Cryostat 999
- 9.3.3.7 Commercial Biomagnetic Measurement Devices 1000
- 9.3.3.7.1 Helmet System: Vectorview 1001
- 9.3.3.7.2 Magnetic Field Imaging (MFI) 1003
- 9.3.3.8 Special Biomagnetic Measurement Devices and Applications 1005
- 9.3.3.8.1 Fetal MCG/MEG – SARA 1005
- 9.3.3.8.2 BabySQUID 1008
- 9.3.3.8.3 Micro-SQUID Systems 1008
- 9.3.3.8.4 The Jena 16-Channel Micro-SQUID Device 1009
- 9.3.3.8.5 Liver Iron Susceptometry 1010
- 9.3.3.8.6 Magnetic Marker Monitoring for Investigation of the Motility in the Human Digestive System 1011
- 9.3.3.8.7 Magnetorelaxometry (MRX) 1011
- 9.3.3.8.8 Low-Field NMR–Low-Field MRI 1012
- 9.3.3.9 High- T_c SQUIDs in Biomagnetism 1012
- 9.3.3.10 Conclusion 1013
- References 1013
- 9.3.4 Geophysical Exploration 1020
Ronny Stolz
- 9.3.4.1 Introduction 1020
- 9.3.4.2 Laboratory Instruments 1020
- 9.3.4.3 Geomagnetism 1021
- 9.3.4.3.1 Gradiometer Configurations 1023
- 9.3.4.4 Electromagnetic Methods 1029
- 9.3.4.4.1 Transient Electromagnetics 1031
- 9.3.4.5 Gravimetry 1036
- 9.3.4.6 Future Impact of SQUID in Geophysics 1037
- References 1038
- 9.3.5 Scanning SQUID Microscopy 1042
John Kirtley
- 9.3.5.1 Introduction 1042
- 9.3.5.2 Magnetic Microscopies 1042
- 9.3.5.3 Brief History of SQUID Microscopy 1043
- 9.3.5.4 Basics 1044
- 9.3.5.4.1 Scanning SQUID Sensors 1044
- 9.3.5.5 Scanning and Thermal Isolation 1046
- 9.3.5.6 Imaging Modes 1046
- 9.3.5.6.1 Magnetometry 1047
- 9.3.5.6.2 Susceptometry 1048
- 9.3.5.7 Applications 1053
- 9.3.5.7.1 Magnetometry 1053
- 9.3.5.7.2 Imaging Susceptibility 1057
- References 1061
- Further Reading 1065

- 9.4 SQUID Thermometers 1066
Thomas Schurig and Jörn Beyer
- 9.4.1 Introduction 1066
- 9.4.2 Some Basic Metrology Aspects 1066
- 9.4.3 The Resistive SQUID Noise Thermometer 1067
- 9.4.4 Quantum Roulette Thermometer 1070
- 9.4.5 Current Sensing Noise Thermometer 1071
- 9.4.6 Magnetic Field Fluctuation Noise Thermometer 1074
References 1079
- 9.5 Radio Frequency Amplifiers Based on DC SQUIDs 1081
Michael Mück and Robert McDermott
- 9.5.1 Introduction 1081
- 9.5.1.1 Amplifying Voltages and Currents with a SQUID 1081
- 9.5.2 The SQUID at Very High Frequencies 1082
- 9.5.3 Practical SQUID rf Amplifiers 1083
- 9.5.4 Coupling Radio Frequency Power to the SQUID 1084
- 9.5.5 Noise Temperature of SQUID Amplifiers 1085
- 9.5.6 Input and Output Impedance of a SQUID rf Amplifier 1087
- 9.5.7 Nonlinearities and Intermodulation in SQUID rf Amplifiers 1088
- 9.5.8 Applications of SQUID Amplifiers 1089
- 9.5.8.1 The Axion Detector 1089
- 9.5.8.2 Reading out Quantum Bits 1090
- 9.5.9 Conclusion 1092
References 1092
- 9.6 SQUID-Based Cryogenic Current Comparators 1096
Wolfgang Vodel, Rene Geithner, and Paul Seidel
- 9.6.1 Principle of the CCC 1096
- 9.6.2 Applications in Metrology 1099
- 9.6.2.1 Resistance Ratio Bridges 1099
- 9.6.2.2 The Quantized Hall Effect (QHE) 1100
- 9.6.2.3 High-Value Resistors and Small Currents 1101
- 9.6.3 CCC for Beam Diagnostics 1101
- 9.6.3.1 CCC for Dark Electrons 1103
- 9.6.3.2 CCC for High-Energy Ions 1103
- 9.6.4 Use of HTS Materials for CCC 1105
- 9.6.5 Integrated CCCs 1107
- 9.6.6 Summary and Outlook 1107
References 1108
- 10 Superconductor Digital Electronics 1111**
- 10.1 Logic Circuits 1111
John X. Przybysz and Donald L. Miller
- 10.1.1 Introduction 1111
- 10.1.2 Latching Logic 1111
- 10.1.3 RSFQ Logic 1112
- 10.1.4 Low-Energy Logic 1117
- 10.1.5 Alternative Low-Power Logic Gates 1120
- 10.1.6 Output Interface Circuits 1122
- 10.1.7 Summary of Logic Gates 1123
References 1123
- 10.2 Superconducting Mixed-Signal Circuits 1125
Hannes Toepfer
- 10.2.1 Introduction 1125
- 10.2.2 Samplers 1125
- 10.2.2.1 General Features 1125
- 10.2.2.2 State-of-the Art 1126
- 10.2.3 Analog-to-Digital Converters 1126
- 10.2.3.1 General Features 1126
- 10.2.3.2 Basic Operation Principles of Superconductive ADCs 1127
- 10.2.3.3 Parallel Conversion – Nyquist Rate Converters 1127
- 10.2.3.3.1 Quantization 1128
- 10.2.3.4 Serial Conversion – Oversampling Converters 1129
- 10.2.3.4.1 Quantization 1129
- 10.2.3.5 Pulse Counting and Decimation 1130
- 10.2.3.6 Technology Constraints and State-of-the Art 1130
- 10.2.3.6.1 LTS Technology 1131
- 10.2.3.6.2 LTS Applications of ADC 1131
- 10.2.3.6.3 HTS Technology 1131
- 10.2.3.6.4 HTS Applications of ADC 1132
- 10.2.4 Conclusion 1132
References 1132
- 10.3 Digital Processing 1135
Oleg Mukhanov
- 10.3.1 Introduction 1135
- 10.3.2 Digital Circuits: SFQ Design Guiding Principles 1136
- 10.3.3 Main Digital Circuit Blocks 1137
- 10.3.3.1 Adders 1137
- 10.3.3.1.1 Serial Adders 1138
- 10.3.3.1.2 Parallel Adders 1139
- 10.3.3.2 Arithmetic Logic Unit (ALU) 1141
- 10.3.3.3 Shift Registers 1141
- 10.3.3.4 Demultiplexers and Multiplexers 1143
- 10.3.3.5 Decoders 1146
- 10.3.3.6 Binary Counters 1146
- 10.3.3.7 Multipliers 1147

10.3.4	Digital Processors	1149
10.3.4.1	Digital Data Processors	1149
10.3.4.1.1	Bit-Serial Processor (Core1)	1150
10.3.4.1.2	Parallel-Serial Processor (Flux-1)	1152
10.3.4.1.3	Reconfigurable Data Path (RDP) Processor	1153
10.3.4.2	Digital Signal Processors	1154
10.3.4.2.1	Time-to-Digital Converters (TDCs)	1154
10.3.4.2.2	Digital Filters	1156
10.3.4.2.3	Digital Channelizers	1157
10.3.4.2.4	Digital Correlators	1157
10.3.5	Conclusions	1159
	References	1160
10.4	Quantum Computing	1163
	<i>Jürgen Lisenfeld</i>	
10.4.1	Introduction	1163
10.4.2	Quantum Computing	1164
10.4.3	Decoherence	1166
10.4.4	Phase Qubits	1167
10.4.4.1	Flux Qubits	1169
10.4.5	Charge Qubits	1170
10.4.6	Transmon Qubits	1172
	References	1173
10.5	Advanced Superconducting Circuits and Devices	1176
	<i>Martin Weides and Hannes Rotzinger</i>	
10.5.1	Introduction	1176
10.5.2	Field-Effect Devices	1177
10.5.2.1	Josephson Field-Effect Transistor	1177
10.5.2.2	NanoSQUIDs	1178
10.5.2.3	Majorana Fermions and Topological Qubits	1178
10.5.3	Quantum Information Circuits	1180
10.5.3.1	Material and Design Considerations	1181
10.5.4	Metamaterials at Microwave Frequencies	1182
10.5.4.1	Classical Metamaterials	1183
10.5.4.2	Quantum Metamaterials	1184
10.5.5	Quantum Phase Slip	1185
10.5.5.1	Basic Concept	1185
10.5.5.2	Phase Slip Flux Qubit	1188
10.5.5.3	Constant Current Steps	1189
	References	1190
10.6	Digital SQUIDs	1194
	<i>Pascal Feuvre</i>	
10.6.1	Introduction	1194

10.6.2	History of Digital SQUIDs	1195
10.6.3	Recent Developments of Digital SQUIDs	1198
10.6.4	An Application of Digital SQUIDs for Studying Natural Hazards	1200
10.6.5	Prospects	1202
	References	1203
11	Other Applications	1207
11.1	Josephson Arrays as Radiation Sources (incl. Josephson Laser)	1207
	<i>Huabing Wang</i>	
11.1.1	Introduction	1207
11.1.2	Arrays That Are Coherent through Classical Coupling	1208
11.1.3	Arrays That Are Coherent Coupling To an External Cavity	1210
11.1.4	Intrinsic Josephson Junctions	1213
11.1.5	Summarization	1223
	Acknowledgment	1223
	References	1224
11.2	Tunable Microwave Devices	1226
	<i>Neeraj Khare</i>	
11.2.1	Introduction	1226
11.2.2	Mechanical/Electromechanical Tuning	1226
11.2.3	Electrical Tuning	1227
11.2.4	Magnetic Tuning	1228
11.2.5	Optical Tuning	1229
	References	1230
12	Summary and Outlook	1233
	<i>Herbert C. Freyhardt</i>	
12.1	Introduction	1233
12.2	Superconducting Materials for Applications	1234
12.3	Superconducting Magnets and Large-Scale Applications	1237
12.4	Superconducting Electronics	1240
	Acknowledgment	1242

Index 1243