
Contents

Introduction	ix
Chapter 1. Dissipation Sources in Electronic Circuits	1
1.1. Brief description of logic types	1
1.1.1. Boolean logic	1
1.1.2. Combinational and sequential logic	7
1.1.3. NMOS and PMOS transistors	15
1.1.4. Complementary CMOS logic	21
1.1.5. Pass-transistor logic	26
1.1.6. Dynamic logic	29
1.2. Origins of heat dissipation in circuits.	32
1.2.1. Joule effect in circuits	32
1.2.2. Calculating dynamic power	34
1.2.3. Calculating static power and its origins	37
Chapter 2. Thermodynamics and Information Theory	39
2.1. Recalling the basics: entropy and information	39
2.1.1. Statistical definition of entropy	39
2.1.2. Macroscopic energy and entropy	42
2.1.3. Thermostat exchange, Boltzmann's law and the equal division of energy	46
2.1.4. Summary and example of energy production in a conductor carrying a current	50
2.1.5. Information and the associated entropy	52
2.2. Presenting Landauer's principle.	57
2.2.1. Presenting Landauer's principle and other examples	57

2.2.2. Experimental validations of Landauer's principle	64
2.3. Adiabaticity and reversibility	66
2.3.1. Adiabatic principle of charging capacitors	66
2.3.2. Adiabaticity and reversibility: a circuit approach	82
Chapter 3. Transistor Models in CMOS Technology	91
3.1. Reminder on semiconductor properties	91
3.1.1. State densities and semiconductor properties	91
3.1.2. Currents in a semiconductor	100
3.1.3. Contact potentials	102
3.1.4. Metal-oxide semiconductor structure	103
3.1.5. Weak and strong inversion	109
3.2. Long- and short-channel static models	114
3.2.1. Basic principle and brief history of semiconductor technology	114
3.2.2. Transistor architecture and Fermi pseudo-potentials	117
3.2.3. Calculating the current in a long-channel static regime	120
3.2.4. Calculating the current in a short-channel regime	129
3.3. Dynamic transistor models	132
3.3.1. Quasi-static regime	132
3.3.2. Dynamic regime	135
3.3.3. "Small signals" transistor model	136
Chapter 4. Practical and Theoretical Limits of CMOS Technology	143
4.1. Speed-dissipation trade-off and limits of CMOS technology	143
4.1.1. From the transistor to the integrated circuit	143
4.1.2. Trade-off between speed and consumption	146
4.1.3. The trade-off between dynamic consumption and static consumption	149
4.2. Sub-threshold regimes	154
4.2.1. Recall of the weak inversion properties	154
4.2.2. Limits to sub-threshold CMOS technology	160
4.3. Practical and theoretical limits in CMOS technology	162
4.3.1. Economic considerations and evolving methodologies	162

4.3.2. Technological difficulties: dissipation, variability and interconnects	164
4.3.3. Theoretical limits and open questions	171
Chapter 5. Very Low Consumption at System Level	177
5.1. The evolution of power management technologies	177
5.1.1. Basic techniques for reducing dynamic power.	177
5.1.2. Basic techniques for reducing static power.	180
5.1.3. Designing in 90, 65 and 45 nm technology.	185
5.2. Sub-threshold integrated circuits	186
5.2.1. Sub-threshold circuit features.	186
5.2.2. Pipeline and parallelization	187
5.2.3. New SRAM structures	187
5.3. Near-threshold circuits	188
5.3.1. Optimization method.	189
5.4. Chip interconnect and networks.	194
5.4.1. Dissipation in the interconnect	194
5.4.2. Techniques for reducing dissipation in the interconnect	199
Chapter 6. Reversible Computing and Quantum Computing	203
6.1. The basis for reversible computing.	203
6.1.1. Introduction	203
6.1.2. Group structure of reversible gates	205
6.1.3. Conservative gates, linearity and affinity	206
6.1.4. Exchange gates	207
6.1.5. Control gates.	210
6.1.6. Two basic theorems: “no fan-out” and “no cloning”	213
6.2. A few elements for synthesizing a function	214
6.2.1. The problem and constraints on synthesis	214
6.2.2. Synthesizing a reversible function	215
6.2.3. Synthesizing an irreversible function	218
6.2.4. The adder example	219
6.2.5. Hardware implementation of reversible gates	222
6.3. Reversible computing and quantum computing	225
6.3.1. Principles of quantum computing	226
6.3.2. Entanglement	227
6.3.3. A few examples of quantum gates	229
6.3.4. The example of Grover’s algorithm	231

Chapter 7. Quasi-adiabatic CMOS Circuits	237
7.1. Adiabatic logic gates in CMOS	237
7.1.1. Implementing the principles of optimal charge and adiabatic pipeline	237
7.1.2. ECRL and PFAL in CMOS	244
7.1.3. Comparison to other gate technologies	250
7.2. Calculation of dissipation in an adiabatic circuit	251
7.2.1. Calculation in the normal regime	251
7.2.2. Calculation in sub-threshold regimes	259
7.3. Energy-recovery supplies and their contribution to dissipation	264
7.3.1. Capacitor-based supply	264
7.3.2. Inductance-based supply	273
7.4. Adiabatic arithmetic architecture	280
7.4.1. Basic principles	280
7.4.2. Adder example	281
7.4.3. The interest in complex gates	283
Chapter 8. Micro-relay Based Technology	285
8.1. The physics of micro-relays	285
8.1.1. Different computing technologies	285
8.1.2. Different actuation technologies	287
8.1.3. Dynamic modeling of micro-electro-mechanical relays	290
8.1.4. Implementation examples and technological difficulties	297
8.2. Calculation of dissipation in a micro-relay based circuit	299
8.2.1. Optimization of micro-relays through electrostatic actuation	299
8.2.2. Adiabatic regime solutions	307
8.2.3. Comparison between CMOS logic and micro-relays	312
Bibliography	317
Index	321