

Contents

Preface	xiii
About the Authors	xv
1 Smart Sensor Systems: Why? Where? How?	1
<i>Johan H. Huijsing</i>	
1.1 Third Industrial Revolution	1
1.2 Definitions for Several Kinds of Sensors	3
1.2.1 Definition of Sensors	3
1.2.2 Definition of Smart Sensors	9
1.2.3 Definition of Integrated Smart Sensors	9
1.2.4 Definition of Integrated Smart Sensor Systems	11
1.3 Automated Production Machines	12
1.4 Automated Consumer Products	16
1.4.1 Smart Cars	16
1.4.2 Smart Homes	16
1.4.3 Smart Domestic Appliances	17
1.4.4 Smart Toys	19
1.5 Conclusion	21
References	21
2 Interface Electronics and Measurement Techniques for Smart Sensor Systems	23
<i>Gerard C.M. Meijer</i>	
2.1 Introduction	23
2.2 Object-oriented Design of Sensor Systems	24
2.3 Sensing Elements and Their Parasitic Effects	25
2.3.1 Compatibility of Packaging	25
2.3.2 Effect of Cable and Wire Impedances	26
2.3.3 Parasitic and Cross-effects in Sensing Elements	27
2.3.4 Excitation Signals for Sensing Elements	29
2.4 Analog-to-digital Conversion	30
2.5 High Accuracy Over a Wide Dynamic Range	33
2.5.1 Systematic, Random and Multi-path Errors	33
2.5.2 Advanced Chopping Techniques	34
2.5.3 Autocalibration	36

2.5.4	<i>Dynamic Amplification</i>	37
2.5.5	<i>Dynamic Division and Other Dynamic Signal-processing Techniques</i>	40
2.6	A Universal Transducer Interface	41
2.6.1	<i>Description of the Interface Chip and the Applied Measurement Techniques</i>	41
2.6.2	<i>Realization and Experimental Results</i>	47
2.7	Summary and Future Trends	50
2.7.1	<i>Summary</i>	50
2.7.2	<i>Future Trends</i>	51
	Problems	51
	References	54
3	Silicon Sensors: An Introduction	55
	<i>Paddy J. French</i>	
3.1	Introduction	55
3.2	Measurement and Control Systems	55
3.3	Transducers	57
3.3.1	<i>Form of Signal-carrying Energy</i>	57
3.3.2	<i>Signal Conversion in Transducers</i>	59
3.3.3	<i>Smart Silicon Sensors</i>	60
3.3.4	<i>Self-generating and Modulating Transducers</i>	63
3.4	Transducer Technologies	63
3.4.1	<i>Introduction</i>	63
3.4.2	<i>Generic Nonsilicon Technologies</i>	64
3.4.3	<i>Silicon</i>	66
3.5	Examples of Silicon Sensors	68
3.5.1	<i>Radiation Domain</i>	68
3.5.2	<i>Mechanical Domain</i>	70
3.5.3	<i>Thermal Domain</i>	70
3.5.4	<i>Magnetic Domain</i>	72
3.5.5	<i>Chemical Domain</i>	74
3.6	Summary and Future Trends	75
3.6.1	<i>Summary</i>	75
3.6.2	<i>Future Trends</i>	75
	References	76
4	Optical Sensors Based on Photon Detection	79
	<i>Reinoud F. Wolffenbuttel</i>	
4.1	Introduction	79
4.2	Photon Absorption in Silicon	81
4.3	The Interface: Photon Transmission Into Silicon	84
4.4	Photon Detection in Silicon Photoconductors	87
4.4.1	<i>Photoconductors in Silicon: Operation and Static Performance</i>	89
4.4.2	<i>Photoconductors in Silicon: Dynamic Performance</i>	93
4.5	Photon Detection in Silicon pn Junctions	93
4.5.1	<i>Defining the Depletion Layer at a pn Junction</i>	94
4.5.2	<i>Electron-hole Collection in the Depletion Layer</i>	97

Contents	vii
4.5.3 <i>Electron–hole Collection in the Substrate</i>	97
4.5.4 <i>Electron–hole Collection Close to the Surface</i>	99
4.5.5 <i>Backside-illuminated Pin Photodiode</i>	100
4.5.6 <i>Electron–hole Collection in Two Stacked pn Junctions</i>	102
4.6 Detection Limit	103
4.6.1 <i>Noise in the Optical Signal</i>	104
4.6.2 <i>Photon Detector Noise</i>	105
4.6.3 <i>Photon Detector Readout</i>	106
4.7 Photon Detectors with Gain	108
4.7.1 <i>The Phototransistor</i>	108
4.7.2 <i>The Avalanche Photodiode</i>	109
4.7.3 <i>Time Integration of Photon-generated Charge</i>	112
4.8 Application Examples	113
4.8.1 <i>Color Sensor in CMOS</i>	113
4.8.2 <i>Optical Microspectrometer in CMOS</i>	115
4.9 Summary and Future Trends	117
4.9.1 <i>Summary</i>	117
4.9.2 <i>Future Trends</i>	118
Problems	119
References	119
5 Physical Chemosensors	121
<i>Michael J. Vellekoop</i>	
5.1 Introduction	121
5.1.1 <i>Thin-film Chemical Interfaces</i>	122
5.1.2 <i>Total Analysis Systems</i>	122
5.2 Physical Chemosensing	123
5.3 Energy Domains	124
5.4 Examples and Applications	126
5.5 Examples of <i>in situ</i> Applications	127
5.5.1 <i>Blood Oximeter</i>	127
5.5.2 <i>Thermal Conductivity Detector</i>	127
5.5.3 <i>Engine Oil Monitoring System</i>	129
5.5.4 <i>Oil-condition Sensor Based on Infrared Measurements</i>	130
5.5.5 <i>Electronic Nose</i>	130
5.6 Microfluidics Devices	131
5.6.1 <i>Projection Cytometer</i>	135
5.6.2 <i>Coulter Counter</i>	138
5.6.3 <i>Dielectrophoresis-based Devices</i>	140
5.6.4 <i>High-throughput Screening Arrays</i>	144
5.6.5 <i>Contactless Conductivity Detection in CE</i>	145
5.7 Conclusions	146
Problems	147
References	147

6 Thermal Sensors	151
<i>Sander (A.W.) van Herwaarden</i>	
6.1 The Functional Principle of Thermal Sensors	151
6.1.1 <i>Self-generating Thermal-power Sensors</i>	151
6.1.2 <i>Modulating Thermal-conductance Sensors</i>	152
6.2 Heat Transfer Mechanisms	153
6.3 Thermal Structures	155
6.3.1 <i>Modeling</i>	155
6.3.2 <i>Floating Membranes</i>	160
6.3.3 <i>Cantilever Beams and Bridges</i>	161
6.3.4 <i>Closed Membranes</i>	163
6.4 Temperature-Difference Sensing Elements	165
6.4.1 <i>Introduction</i>	165
6.4.2 <i>Thermocouples</i>	165
6.4.3 <i>Other Elements</i>	168
6.5 Sensors Based on Thermal Measurements	168
6.5.1 <i>Microcalorimeter</i>	169
6.5.2 <i>Psychrometer</i>	170
6.5.3 <i>Infrared Sensor</i>	171
6.5.4 <i>RMS Converter</i>	172
6.5.5 <i>EM Field Sensor</i>	173
6.5.6 <i>Flow Sensor</i>	174
6.5.7 <i>Vacuum Sensor</i>	174
6.5.8 <i>Thermal Conductivity Gauge</i>	176
6.5.9 <i>Acceleration Sensors</i>	177
6.5.10 <i>Nanocalorimeter</i>	177
6.6 Summary and Future Trends	179
6.6.1 <i>Summary</i>	179
6.6.2 <i>Future Trends</i>	179
Problems	180
References	182
7 Smart Temperature Sensors and Temperature-Sensor Systems	185
<i>Gerard C.M. Meijer</i>	
7.1 Introduction	185
7.2 Application-related Requirements and Problems of Temperature Sensors	188
7.2.1 <i>Accuracy</i>	189
7.2.2 <i>Short-term and Long-term Stability</i>	189
7.2.3 <i>Noise and Resolution</i>	190
7.2.4 <i>Self-heating</i>	192
7.2.5 <i>Heat Leakage along the Connecting Wires</i>	194
7.2.6 <i>Dynamic Behavior</i>	194
7.3 Resistive Temperature-sensing Elements	196
7.3.1 <i>Practical Mathematical Models</i>	196
7.3.2 <i>Linearity and Linearization</i>	198

7.4	Temperature-sensor Features of Transistors	200
7.4.1	<i>General Considerations</i>	200
7.4.2	<i>Physical and Mathematical Models</i>	201
7.4.3	<i>PTAT Temperature Sensors</i>	203
7.4.4	<i>Temperature Sensors with an Intrinsic Voltage Reference</i>	207
7.4.5	<i>Calibration and Trimming of Transistor Temperature Sensors</i>	208
7.5	Smart Temperature Sensors and Systems	208
7.5.1	<i>A Smart Temperature Sensor with a Duty-cycle-modulated Output Signal</i>	209
7.5.2	<i>Smart Temperature-sensor Systems with Discrete Elements</i>	212
7.6	Case Studies of Smart-sensor Applications	212
7.6.1	<i>Thermal Detection of Micro-organisms with Smart Sensors</i>	213
7.6.2	<i>Control of Substrate Temperature</i>	217
7.7	Summary and Future Trends	220
7.7.1	<i>Summary</i>	220
7.7.2	<i>Future Trends</i>	221
	Problems	222
	References	223
8	Capacitive Sensors	225
	<i>Xiujun Li and Gerard C.M. Meijer</i>	
8.1	Introduction	225
8.2	Basics of Capacitive Sensors	226
8.2.1	<i>Principles</i>	226
8.2.2	<i>Precision of Capacitive Sensors</i>	226
8.3	Examples of Capacitive Sensors	227
8.3.1	<i>Angular Encoders</i>	228
8.3.2	<i>Humidity Sensors</i>	229
8.3.3	<i>Liquid-level Gauges</i>	230
8.4	The Design of Electrode Configurations	231
8.4.1	<i>EMI Effects</i>	231
8.4.2	<i>Electric-field-bending Effects</i>	232
8.4.3	<i>Active-guard Electrodes</i>	232
8.4.4	<i>Floating Electrodes</i>	233
8.4.5	<i>Contamination and Condensation</i>	234
8.5	Reduction of Field-bending Effects: Segmentation	234
8.5.1	<i>Three-layered Electrode Structures</i>	235
8.5.2	<i>A Model for the Electrostatic Field in Electrode Structures</i>	236
8.5.3	<i>Influence of the Electric-field-bending Effects on Linearity</i>	237
8.6	Selectivity for Electrical Signals and Electrical Parameters	237
8.6.1	<i>Selective Detection of Band-limited Frequencies</i>	238
8.6.2	<i>Selective Detection of a Selected Parameter</i>	239
8.6.3	<i>Measurement Techniques to Reduce the Effects of Shunting Conductances</i>	240
8.7	Summary and Future Trends	246
	Problems	246
	References	247

9	Integrated Hall Magnetic Sensors	249
	<i>Radivoje S. Popović and Pavel Kejik</i>	
9.1	Introduction	249
9.2	Hall Effect and Hall Elements	250
	9.2.1 <i>The Hall Effect</i>	250
	9.2.2 <i>Hall Elements</i>	253
	9.2.3 <i>Characteristics of Hall Elements</i>	253
	9.2.4 <i>Integrated Horizontal Hall Plates</i>	256
	9.2.5 <i>Integrated Vertical Hall Plates</i>	258
9.3	Integrated Hall Sensor Systems	259
	9.3.1 <i>Biasing a Hall Device</i>	260
	9.3.2 <i>Reducing Offset and 1/f noise</i>	260
	9.3.3 <i>Amplifying the Hall Voltage</i>	262
	9.3.4 <i>Integrating Magnetic Functions</i>	265
9.4	Examples of Integrated Hall Magnetic Sensors	267
	9.4.1 <i>Magnetic Angular Position Sensor</i>	267
	9.4.2 <i>Fully Integrated Three-axis Hall Probe</i>	269
	9.4.3 <i>Integrated Hall Probe for Magnetic Microscopy</i>	271
	Problems	276
	References	276
10	Universal Asynchronous Sensor Interfaces	279
	<i>Gerard C.M. Meijer and Xiujun Li</i>	
10.1	Introduction	279
10.2	Universal Sensor Interfaces	280
10.3	Asynchronous Converters	283
	10.3.1 <i>Conversion of Sensor Signals to the Time Domain</i>	284
	10.3.2 <i>Wide-range Conversion of Sensor Signals to the Time Domain for Very Small or Very Large Signals</i>	287
	10.3.3 <i>Output Signals</i>	288
	10.3.4 <i>Quantization Noise of Sampled Time-modulated Signals</i>	290
	10.3.5 <i>A Comparison between Asynchronous Converters and Sigma–delta Converters</i>	294
10.4	Dealing with Problems of Low-cost Design of Universal Interface ICs	296
10.5	Front-end Circuits	297
	10.5.1 <i>Cross-effects and Interaction</i>	297
	10.5.2 <i>Interference</i>	298
	10.5.3 <i>Optimization of Components, Circuits and Wiring</i>	298
10.6	Case Studies	299
	10.6.1 <i>Front-end Circuits for Capacitive Sensors</i>	299
	10.6.2 <i>Front-end Circuits for Resistive Bridges</i>	302
	10.6.3 <i>A Front-end Circuit for a Thermocouple-voltage Processor</i>	305
10.7	Summary and Future Trends	307
	10.7.1 <i>Summary</i>	307
	10.7.2 <i>Future Trends</i>	307
	Problems	308
	References	311

11 Data Acquisition for Frequency- and Time-domain Sensors	313
<i>Sergey Y. Yurish</i>	
11.1 Introduction	313
11.2 DAQ Boards: State of the Art	314
11.3 DAQ Board Design for Quasi-digital Sensors	316
11.3.1 <i>Advanced Methods for Frequency-to-digital Conversion</i>	316
11.3.2 <i>Examples</i>	322
11.3.3 <i>Methods for Duty-cycle-to-digital Conversion</i>	324
11.3.4 <i>Methods for Phase-shift-to-digital Conversion</i>	326
11.4 Universal Frequency-to-digital Converters (UFDC)	330
11.4.1 <i>ICs for Frequency-to-digital Conversion: State of the Art</i>	332
11.4.2 <i>UFDC: Features and Performances</i>	333
11.5 Applications and Examples	335
11.6 Summary and Future Trends	338
Problems	339
References	340
12 Microcontrollers and Digital Signal Processors for Smart Sensor Systems	343
<i>Ratcho M. Ivanov</i>	
12.1 Introduction	343
12.2 MCU and DSP Architectures, Organization, Structures, and Peripherals	344
12.3 Choosing a Low-Power MCU or DSP	347
12.3.1 <i>Average Current Consumption</i>	348
12.3.2 <i>Oscillator and System Clocks</i>	349
12.3.3 <i>Interrupts</i>	350
12.3.4 <i>Peripherals</i>	350
12.3.5 <i>Summary</i>	350
12.4 Timer Modules	351
12.4.1 <i>Introduction to Timer Modules</i>	351
12.4.2 <i>Examples of Timer Module Applications for Various Microcontrollers</i>	355
12.5 Analog Comparators, ADCs, and DACs as Modules of Microcontrollers	370
12.5.1 <i>Introduction</i>	370
12.5.2 <i>Application Examples of Analog Modules</i>	370
12.6 Embedded Networks and LCD Interfacing	373
12.7 Development Tools and Support	374
12.8 Conclusions	374
References Sites	374
Appendix A Material Data	375
Appendix B Conversion for non-SI Units	377
Index	379

Solutions to Problems can be found on the Companion website

