

Halit Eren

Electronic Portable Instruments

Design and Applications



CRC PRESS

Contents

1	Measurements, Instrumentation, and Electronic Portable Instruments.....	1
1.1	Fundamentals of Measurements.....	1
1.2	Units and Standards.....	2
1.3	General Concepts on Instruments.....	6
1.3.1	Types of Instruments.....	8
1.3.2	Analog Instruments.....	9
1.3.3	Digital Instruments.....	11
1.4	Introduction to Portable Instruments.....	13
1.4.1	Design Consideration of Electronic Portable Instruments.....	14
1.5	Response and Drift.....	18
1.5.1	Static Response.....	19
1.5.2	Dynamic Response.....	20
1.5.3	Drift.....	23
1.6	Errors and Uncertainty.....	23
1.6.1	Systematic Errors.....	24
1.6.1.1	Uncertainty.....	26
1.6.1.2	Calibration Error in Sensors.....	26
1.6.2	Random Errors.....	26
1.6.3	Gross Errors.....	27
1.6.4	Error Reduction Techniques.....	27
1.7	Calibration and Testing of Instruments.....	28
1.7.1	Testing of Instruments.....	29
1.8	Controlling and Networking of Instruments.....	31
1.9	Signals and Signal Conditioning.....	33
1.9.1	Types of Signals.....	33
1.9.1.1	Multichannel and Multidimensional Signals.....	33
1.9.1.2	Continuous or Discrete Signals.....	34
1.9.1.3	Deterministic and Random Signals.....	35
1.9.1.4	Transient Signals.....	35
1.9.2	Signal Classification.....	35
1.9.2.1	Single-Ended and Differential Signals.....	36
1.9.2.2	Narrowband and Broadband Signals.....	36
1.9.2.3	Low- and High-Output Impedance Signals.....	36
1.9.2.4	Signal Conditioning at the Sensor Level.....	36
1.10	Noise and Interference.....	37
1.10.1	Noise.....	37
1.10.1.1	Thermal Noise.....	37
1.10.1.2	Shot Noise.....	38

1.10.1.3	Excess Noise	38
1.10.1.4	Burst Noise	38
1.10.1.5	Partition Noise	38
1.10.1.6	Generation-Recombination Noise	39
1.10.1.7	Spot Noise.....	39
1.10.1.8	Total Noise.....	39
1.10.1.9	Noise Bandwidth.....	40
1.10.1.10	Spectral Density	40
1.10.2	Interference.....	40
2	Sensors, Transducers, and Electronic Portable Instruments....	43
	Introduction	43
2.1	Voltage and Current Sensors	44
2.1.1	Voltage Sensors	44
2.1.1.1	Electronic Voltmeters	48
2.1.2	Current Sensors	49
2.1.2.1	Power and Power Factor Measurements	50
2.2	Magnetic Sensors	51
2.2.1	Primary Magnetic Sensors	51
2.2.1.1	Hall-Effect Sensors	52
2.2.1.2	Magnetodiodes and Magnetotransistor Sensors	53
2.2.1.3	Magnetoresistive Sensors	53
2.2.1.4	Magneto-Optical Sensors	54
2.2.1.5	Integrated Magnetic Field Sensors	54
2.2.1.6	Magnetic Thin Films	54
2.2.2	Secondary Magnetic Sensors	55
2.2.2.1	Linear and Rotary Variable-Reluctance Sensors	57
2.2.2.2	Linear Variable-Differential Transformer	59
2.3	Capacitive and Charge Sensors	59
2.3.1	Integrated Circuit and Computable Capacitors.....	61
2.4	Semiconductor and Intelligent Sensors.....	62
2.4.1	Semiconductor Sensors	62
2.4.1.1	Piezoelectric Sensors	63
2.4.1.2	Capacitive IC Sensors	64
2.4.1.3	Chemical Sensors.....	65
2.4.1.4	Resonance Sensors.....	65
2.4.1.5	Electrical Oscillators.....	65
2.4.2	Embedded Sensing.....	66
2.4.3	Sensing Arrays.....	66
2.4.4	Amorphous Material Sensors.....	67
2.4.5	Intelligent Sensors	67
2.5	Acoustic Sensors	68
2.5.1	Capacitor Microphones	71
2.5.2	Piezoelectric and Electret Microphones.....	72
2.5.3	Fiber-Optic Microphones	72
2.5.4	Ultrasonic Sensors.....	73

2.6	Temperature and Heat Sensors	74
2.6.1	Temperature Sensors.....	74
2.6.1.1	Thermocouples.....	76
2.6.1.2	Thermoresistive Sensors.....	77
2.6.1.3	Silicon Resistive Sensors	78
2.6.1.4	Thermistors.....	79
2.6.1.5	Semiconductor Temperature Sensors.....	79
2.6.2	Heat Sensors.....	80
2.6.2.1	Pyroelectric Sensors	81
2.6.2.2	Thermopile Sensors.....	82
2.6.2.3	Active Infrared Sensors	83
2.6.2.4	Bolometers	83
2.7	Light Sensors	83
2.7.1	Photosensors	85
2.7.1.1	Photodiodes/Phototransistors	85
2.7.1.2	Photovoltaic Cells.....	86
2.7.1.3	Photoresistors/Photoconductors	87
2.7.2	Solid-State Light Emitters	87
2.7.3	Image Sensors	88
2.7.4	Spectrometers.....	89
2.7.4.1	Spectroscopic Instruments	89
2.7.5	Optical Fiber Sensors.....	91
2.7.6	Optoisolators.....	93
2.7.7	Photoemissive Sensors and Photomultipliers	93
2.8	Radiation Sensors	93
2.8.1	Particle Radiation	94
2.8.2	Electromagnetic Radiation.....	94
2.8.3	Gas-Filled Detectors.....	96
2.8.4	Semiconductor Radiation Sensors	97
2.8.5	Scintillation Detectors.....	97
2.9	Chemical Sensors.....	98
2.9.1	Enzyme Sensors.....	99
2.9.2	Catalytic Chemical Sensors	99
2.9.3	Electrochemical Sensors	100
2.9.4	Chromatographic Sensors.....	100
2.9.5	Radioactive Chemical Sensors	101
2.9.6	Chemosensors	101
2.9.7	Sensors Based on Light and Properties of Optics	101
2.9.7.1	Absorption and Emission Sensors.....	103
2.9.7.2	Spectrometric Sensors.....	103
2.9.7.3	Colorimetry or Photometry	103
2.10	Gas Sensors.....	103
2.10.1	Infrared, Fluorescent, and Light Absorption Gas Sensors	104
2.10.2	Indicator Tube Gas Sensors	104
2.10.3	Semiconductor Gas Sensors	105
2.10.3.1	Conductometric Sensors.....	105

2.10.3.2	Amperimetric Sensors	105
2.10.3.3	Potentiometric Sensors	107
2.10.4	Ring Oven and Titration Methods	109
2.10.4.1	Titration	109
2.10.5	Application of Gas Detectors	109
2.11	Biomedical and Biological Sensors	110
2.12	Environmental Sensors	111
2.12.1	Time	111
2.12.2	Electromagnetic Field Sensors	112
2.12.2.1	Fluxgate Magnetometer	113
2.12.2.2	Search Coil Magnetometers	114
2.12.3	Humidity and Moisture Sensors	114
2.12.3.1	Conductive Humidity and Moisture Sensors	115
2.12.3.2	Capacitive Humidity and Moisture Sensors	116
2.12.4	Soil Acidity and Alkalinity	117
2.12.5	Fire and Smoke Sensors	118
2.13	Pollution Sensors	119
2.13.1	Air Pollution	119
2.13.2	Water Pollution	120
2.13.3	Soil Pollution	121
2.14	Distance and Rotation Sensors	121
2.14.1	Large-Scale Distance Sensors	122
2.14.2	Small-Scale Distance Sensors	123
2.14.3	Rotation Sensors	123
2.15	Navigational Sensors	124
2.15.1	Inertial Navigation Sensors	124
2.15.2	Gyroscopes	125
2.15.3	Satellite Navigation and Radiolocation	127
2.15.4	Global Positioning Systems	128
2.15.4.1	GPS Receivers	129
2.15.5	Satellite Relay Systems	130
2.16	Mechanical Variables Sensors	131
2.16.1	Position, Displacement, and Proximity Sensors	131
2.16.1.1	Capacitive Position, Displacement, and Proximity Sensors	132
2.16.1.2	Magnetic Position, Displacement, and Proximity Sensors	133
2.16.1.3	Other Position, Displacement, and Proximity Sensors	134
2.16.2	Pressure Sensors	136
2.16.2.1	Low-Pressure Sensors	137
2.16.2.2	High-Pressure Sensors	138
2.16.3	Force Sensors	139
2.16.4	Acceleration Sensors	140
2.16.4.1	Seismic Accelerometers	141

2.16.4.2	Piezoresistive Accelerometers	141
2.16.4.3	Piezoelectric Accelerometers	141
2.16.4.4	Microaccelerometers.....	142
2.16.4.5	Vibrating Beam Accelerometer.....	143
2.16.4.6	Differential-Capacitance Accelerometers.....	144
2.16.5	Stress and Strain Sensors	145
2.16.6	Mass and Weight Sensors	145
2.16.7	Density Sensors	146
2.16.7.1	Magnetic Methods.....	147
2.16.7.2	Vibrational Methods	147
2.16.7.3	Pycnometric Densitometers	148
2.16.7.4	Hydrostatic Weighing Densitometers	148
2.16.7.5	Hydrometers	148
2.16.7.6	Column Type Densitometers.....	149
2.16.7.7	Refractometric Method.....	149
2.16.7.8	Absorption Type Densitometer.....	150
2.16.8	Viscosity Sensors	150
3	Digital Aspects: Hardware, Software, and Electronic	
	Portable Instruments	151
	Introduction	151
3.1	Microprocessors, Microcontrollers, and Computers.....	152
3.1.1	Microprocessors and Microcontroller Architecture.....	153
3.1.2	Microcontrollers.....	155
3.1.2.1	Fabrication Techniques	157
3.1.2.2	Architecture Features	157
3.1.2.3	Input/Output.....	160
3.1.2.4	Interrupts	161
3.1.3	Examples of Microcontrollers	161
3.1.3.1	Cypress's CY8C25xxx/26xxx.....	161
3.1.3.2	Atmel's AVR 8-Bit RISC	163
3.1.3.3	Hitachi's H8/300H.....	163
3.1.3.4	Motorola's MC9S12DP256.....	164
3.1.3.5	AT91 ARM Thumb	164
3.1.3.6	Motorola's MC68F333.....	165
3.1.4	Embedded Controllers	165
3.1.5	Dedicated Computers and Electronic Portable	
	Instruments	167
3.1.6	Digital Signal Processors (DSPs)	170
3.1.7	Types of DSPs and Examples.....	171
3.1.7.1	Data Handling of DSPs	172
3.1.7.2	Implementation of DSPs	174
3.2	Signal Conversion.....	176
3.2.1	Sample-and-Hold Circuits	177
3.2.2	Analog-to-Digital Converters.....	178
3.2.2.1	Counterramp A/D Converters	179

3.2.2.2	Successive Approximation A/D Converters (Serial).....	181
3.2.2.3	Flash A/D Converters (Parallel).....	182
3.2.2.4	Delta-Sigma A/D Converters.....	183
3.2.3	Digital-to-Analog Converters.....	185
3.2.3.1	Weighted Current D/A Converters.....	186
3.2.4	Data Acquisition Systems.....	188
3.2.4.1	Single-Channel Systems.....	188
3.2.4.2	Multichannel Systems.....	189
3.2.5	Data Acquisition Boards.....	190
3.3	Digital Signal Processing.....	192
3.3.1	Continuous-Time Signals.....	194
3.3.2	Discrete-Time Signals.....	196
3.3.3	Energy and Power Signals.....	197
3.3.4	Digital Signals.....	197
3.3.5	Nonperiodic and Random Signals.....	197
3.3.6	Sampling Process.....	198
3.3.7	Reconstruction of Signals.....	201
3.3.8	Quantization.....	202
3.3.9	Coding.....	204
3.3.9.1	Unipolar Codes.....	204
3.3.9.2	Bipolar Codes.....	205
3.3.10	Digital Filters.....	205
3.3.11	Digital Signal Generation.....	206
3.3.12	Data Storage.....	208
3.3.13	Handling Small Signals.....	210
3.4	Instrument Communication and Telemetry.....	211
3.4.1	Protocols.....	211
3.4.2	Communication Networks.....	213
3.4.2.1	SCADA Systems.....	214
3.4.2.2	Fieldbuses.....	215
3.4.3	Telemetry.....	216
3.4.3.1	Multiple-Channel Telemetry.....	218
3.5	IEEE-1451 Standards for Sensors and Actuators: Smart Transducer Interface.....	219
3.6	Virtual Instruments and Portable Instruments.....	220
3.6.1	Data Acquisition Boards for Virtual Instruments.....	221
3.6.2	Software for Virtual Instruments.....	222
3.6.3	Software for Electronic Portable Instruments.....	224
4	Design and Construction of Electronic Portable Instruments.....	229
	Introduction.....	229
4.1	Design Considerations.....	230
4.1.1	Reliability.....	233
4.1.2	Failure Mode Analysis.....	234

4.1.3	System Voltage.....	235
4.1.4	Temperature	236
4.1.5	Humidity and Moisture	236
4.1.6	Corrosive Fumes and Aerosols	237
4.2	Power Supplies and Energy Sources.....	237
4.2.1	Batteries.....	240
4.2.1.1	Carbon-Zinc Batteries	241
4.2.1.2	Alkaline Manganese Dioxide Batteries.....	242
4.2.1.3	Nickel-Cadmium Batteries	242
4.2.1.4	Lead-Acid Batteries	242
4.2.1.5	Lithium Batteries	243
4.2.1.6	Mercury and Silver Oxide Batteries	243
4.2.1.7	Miniature Power Supplies	243
4.2.2	Batteries and Power Management	243
4.2.2.1	Switching Regulation.....	245
4.2.2.2	Programmable Power Management Chipsets	246
4.2.3	Unconventional Power Sources for Portable Instruments	247
4.2.3.1	Solar Cells	247
4.2.3.2	Fuel Cells	247
4.3	Passive Circuit Components.....	248
4.3.1	Resistors.....	249
4.3.1.1	Carbon Composition Resistors.....	249
4.3.1.2	Metal-Film Resistors	249
4.3.1.3	Thin-Film Resistors	250
4.3.1.4	Wire-Wound Resistors	250
4.3.1.5	Foil Resistors	250
4.3.1.6	Variable Resistors, Trimmers, and Potentiometers	251
4.3.2	Capacitors.....	251
4.3.2.1	Ceramic and Glass Capacitors	252
4.3.2.2	Paper Capacitors.....	252
4.3.2.3	Electrolytic Capacitors.....	253
4.3.2.4	Mica Capacitors	253
4.3.2.5	Metallized-Film Capacitors.....	254
4.3.2.6	Variable and Air Core Capacitors.....	254
4.3.2.7	Integrated Circuit Capacitors	255
4.3.2.8	Voltage-Variable Capacitors.....	255
4.3.2.9	Characteristics of Capacitors.....	256
4.3.3	Inductors.....	259
4.4	Active Components and Circuit Design.....	259
4.4.1	Active Analog Components	262
4.4.1.1	Operational Amplifiers and Circuits.....	262
4.4.1.2	Instrumentation Amplifiers	263
4.4.1.3	Isolators	264
4.4.1.4	Circuit Protection ICs	264

4.4.1.5	Single-Chip Active and Passive Device ICs.....	265
4.4.2	Actuators and Controllers	266
4.4.2.1	Mechanical Relays	266
4.4.2.2	On-Off Switches	266
4.4.2.3	Solenoids	266
4.4.3	Fundamental Analog Circuits	267
4.4.3.1	Amplifiers	267
4.4.3.2	Charge Amplifiers	268
4.4.3.3	Voltage Followers	269
4.4.3.4	Filters	270
4.4.3.5	Oscillators	271
4.4.3.6	Pulse Width Modulators and Linearizers	273
4.4.3.7	Bridges.....	273
4.5	Digital Aspects, Communication, and Networks	275
4.5.1	Digital Aspects.....	275
4.5.1.1	Low-Power Digital Components	277
4.5.1.2	Back-Plane Buses	278
4.5.2	Signal Conversion	278
4.5.2.1	Digital-to-Analog Converters	279
4.5.2.2	Analog-to-Digital Converters	279
4.5.2.3	Multiplexers.....	281
4.5.2.4	Sample-Hold Devices.....	281
4.5.2.5	Software to Drive A/D Converters	281
4.5.3	Intelligent Sensors	281
4.5.4	Communications	283
4.5.5	Protocols	284
4.5.5.1	Built-in-Tests.....	286
4.5.6	Networks	287
4.6	Operator Interface.....	288
4.6.1	Displays	291
4.6.1.1	Light-Emitting Diodes	291
4.6.1.2	Liquid Crystal Displays	291
4.7	Construction and Assembly.....	294
4.7.1	Enclosures and Casing	295
4.7.1.1	Weight and Size	298
4.7.2	On-Board Circuit Layout	298
4.7.2.1	Wiring of Connectors and Components.....	299
4.7.2.2	Circuit Boards	299
4.7.3	Interference and Noise Protection.....	300
4.7.3.1	Bypass Capacitors	302
4.7.3.2	Grounding	302
4.7.3.3	Shielding	303
4.8	Software Aspects.....	306
4.8.1	Software for User Interface.....	308

5	Examples and Applications of Portable Instruments.....	311
	Introduction	311
5.1	Laboratory Instruments	312
5.1.1	Multimeters	312
5.1.2	Power and Energy Meters	314
5.1.3	Oscilloscopes	315
5.1.4	Spectrum Analyzers	318
5.1.4.1	Analog Spectrum Analyzers	318
5.1.4.2	Digital Spectrum Analyzers	320
5.2	Environmental Instruments	323
5.2.1	Water Analyzers	323
5.2.2	Soil Analyzers	325
5.2.2.1	Soil Resistivity Instruments	325
5.2.2.2	Soil Moisture Instruments	326
5.2.2.3	Soil Chemistry Analysis Instruments	327
5.2.3	Air Analyzers	327
5.3	Chemical Instruments	329
5.3.1	Portable Chemical Laboratories	332
5.3.2	Gas Detectors	333
5.4	Biomedical Instruments	334
5.4.1	Human Biotelemetry	338
5.4.2	Animal Biotelemetry	342
5.5	Mechanical, Sound, and Vibration Measurement Instruments	343
5.5.1	Mechanical Measurement Instruments	343
5.5.2	Vibration Measurement Instruments	346
5.5.3	Sound Measurement Instruments	348
5.6	Radiation, Light, and Temperature Instruments	350
5.6.1	Long-Wave Radiation Instruments	350
5.6.2	Short-Wave Radiation Sensing	352
5.6.3	Dosimeters	353
5.6.4	Temperature Measurements	354
5.7	GPS and Telemetry-Based Instruments	354
5.8	Computer-Based and Intelligent Instruments	357
5.9	Domestic, Personal, Hobby, and Leisure Portable Instruments	359
6	Conclusions and Future Directions	363
	Bibliography	365
	Index	373