

**SELECT**

***Introduction to  
Measurement  
Science and  
Engineering***

**P.H. Sydenham  
N.H. Hancock  
R. Thorn**



**WILEY**

*Publishers Since 1807*

# CONTENTS

<b>AUTHORS' PREFACE</b>		<b>xi</b>
<b>SERIES EDITOR'S PREFACE</b>		<b>xiii</b>
<b>LIST OF FIGURES</b>		<b>xv</b>
<b>PART A: PHILOSOPHICAL AND THEORETICAL APPRECIATION</b>		
<b>Chapter 1</b>	<b>Introduction</b>	<b>3</b>
1.1	Measurement science and instrument engineering	3
1.2	Measurement technology and measurement science	6
1.3	On the universal importance of measurement	11
1.3.1	The role of measurement science	11
1.3.2	The role of measurement in the newer sciences	12
1.3.3	The role of measurement in achieving control	14
1.3.4	The need for a National Measurement System	16
1.3.5	On the need to improve the quality of measurement	16
1.4	A brief history of measurement science and instrument engineering	17
1.4.1	A sense of history is needed	17
1.4.2	First instruments - ancient times	18
1.4.3	Experimental science begins - Middle Ages to AD 1800	18
1.4.4	Foundations of electrical method - nineteenth century AD	22
1.4.5	Electronics and information technology - the twentieth century	25
	Tutorial examples	29
	References	30
	Bibliography	30
<b>Chapter 2</b>	<b>Fundamental concepts</b>	<b>31</b>
2.1	Introductory remarks	31
2.2	Definitions	31
2.2.1	Signal	31
2.2.2	Data	32
2.2.3	Calibration	32
2.2.4	Information	33
2.2.5	Knowledge	34
2.2.6	An everyday example	34

2.3	Referents, measurands and the measurement process algorithm	36
2.3.1	The system to be measured and its model	37
2.3.2	Referents	38
2.3.3	Measurands	38
2.3.4	The measurement process algorithm	39
2.3.5	An MPA application example	39
2.4	Measurement systems as information machines	43
2.5	Basic measurement terminology	44
2.5.1	Discrimination	44
2.5.2	Repeatability and reproducibility	45
2.5.3	Precision	45
2.5.4	Accuracy	45
2.5.5	Error and uncertainty	46
2.6	Standards, units and their maintenance	47
	Tutorial examples	51
	References	52
<b>Chapter 3</b>	<b>Signals and information</b>	<b>53</b>
3.1	Introduction	53
3.2	Classification of signals	54
3.2.1	Types of signal	54
3.2.2	Signals in the frequency domain	57
3.2.3	Signals in the time domain	62
3.2.4	Transforming signal information between frequency and time domains	68
3.3	Characteristics of signals	68
3.3.1	Deterministic and randomly varying signals	68
3.3.2	The description of multidimensional signals	71
3.3.3	Some important signals	73
3.4	Signal behaviour within systems	75
3.4.1	On system linearity	75
3.4.2	Time-domain response	76
3.4.3	Frequency-domain response	77
3.4.4	Laplace transforms	81
3.4.5	Feedback	86
3.5	Communication theory aspects of signals	88
3.5.1	Communications systems	88
3.5.2	Basics of information theory	91
3.5.3	Coding and decoding of signals	96
3.5.4	Modulation theory	100
	Tutorial examples	105
	References	106

<b>Chapter 4</b>	<b>The information machine</b>	<b>107</b>
4.1	Introduction	107
4.2	The architecture of IT machines	107
4.2.1	Measuring systems are formed of connected blocks	107
4.2.2	Building blocks	108
4.2.3	The transfer characteristic and the transfer function	108
4.2.4	Connections	111
4.3	Static behaviour	114
4.3.1	Describing static and dynamic behaviour	114
4.3.2	Gain and sensitivity	114
4.3.3	Bandwidth	115
4.3.4	Offset	116
4.3.5	Drift	117
4.3.6	Impedance	117
4.3.7	Dynamic range, span, FSD	119
4.4	Dynamic behaviour	119
4.4.1	Rise time	119
4.4.2	Slew rate	120
4.4.3	Formal characterization of dynamic response	120
4.4.4	Zero-order response	122
4.4.5	First-order response	124
4.4.6	Second-order response	130
4.4.7	Higher-order systems	140
4.4.8	Gaussian response	140
4.5	The sensing interface	144
4.5.1	The popular definition model	144
4.5.2	The energy/information model	145
4.5.3	The set-theoretical model	147
4.6	Error and uncertainty within the information machine	148
4.6.1	Classification of errors	148
4.6.2	Origins of error	153
4.6.3	Error propagation and sensitivity analysis	160
4.6.4	Error reduction strategies	164
	<b>Tutorial examples</b>	<b>171</b>
	<b>References</b>	<b>172</b>
<b>Chapter 5</b>	<b>Modelling the measurement system</b>	<b>173</b>
5.1	Introductory remarks	173
5.1.1	Importance of modelling	173
5.1.2	Types of model	173
5.2	Development of a measurement system block diagram	180
5.2.1	Classification of system elements	180
5.2.2	Matrix representation of measurement systems	182
5.2.3	Self-generating and modulated stages	185
5.2.4	Symbology and notation for system description	185
5.3	Generating functional mathematical models	187
5.3.1	Introductory remarks	187
5.3.2	Mathematical modelling of individual blocks	187
5.3.3	Experimental determination of model parameters	197

5.4	Specific transducer computer-aided design tools	198
5.4.1	Using computers to assist instrument modelling	198
5.4.2	The MEDIEM CAD package	199
5.4.3	Finite-element CAD packages	202
5.5	The mathematical model as a functional part of a working measurement system	204
	Tutorial examples	207
	References	208

## PART B: PRACTICAL APPRECIATION

<b>Chapter 6</b>	<b>Handling and processing information</b>	<b>211</b>
6.1	The alternative technologies	211
6.1.1	The energy forms	211
6.1.2	Abstract simulation of the various energy forms	213
6.1.3	Mixing energy forms	213
6.2	Electrical regime	217
6.2.1	Direct current systems	217
6.2.2	Alternating current systems	218
6.2.3	Active network elements	220
6.2.4	Other componentry	221
6.2.5	Building-block approach	221
6.2.6	Electronic systems development	223
6.2.7	A simple electronic instrument example	225
6.3	Fine mechanical regime	228
6.3.1	Basis of mechanical design	228
6.3.2	Componentry of fine mechanics and its design	231
6.3.3	Materials a limitation	232
6.3.4	A strain-meter example of fine mechanics	235
6.4	Radiation regime	237
6.4.1	The forms of radiation used in instruments	237
6.4.2	Basis of design	238
6.4.3	Componentry	240
6.4.4	Practical application	244
6.4.5	System development	246
6.5	Chemical regime	246
6.5.1	General approach	246
6.5.2	Separating the constituents	247
6.5.3	Detection	248
	Tutorial examples	250
	References	250
<b>Chapter 7</b>	<b>Creating measurement systems</b>	<b>251</b>
7.1	Introduction to design	251
7.1.1	Definition of design	251
7.1.2	The design process	252
7.1.3	Design infrastructure	256

7.2	Managing design	262
7.2.1	The design-process flow chart	264
7.2.2	Reticulation of the design task	264
7.3	Specifying the need	266
7.3.1	Knowledge-needed basis of engineering requirement	266
7.3.2	Specifications	266
7.4	Computer-aided design	268
7.4.1	Role of computers	268
7.4.2	Some relevant software tools	269
7.5	Prototyping	273
7.5.1	Need for test models – the prototype	273
7.5.2	Prototyping in the various regimes	274
7.5.3	Into production	282
	<b>Tutorial examples</b>	<b>283</b>
	<b>References</b>	<b>284</b>
<b>Chapter 8</b>	<b>Selection and testing of instrumentation</b>	<b>285</b>
8.1	Critical approach to instrumentation	285
8.1.1	Introductory remarks	285
8.1.2	Guilty until proven innocent	286
8.2	Specification of selection and performance	287
8.2.1	Assessing what is offered	287
8.2.2	Assessment checklist	287
8.3	Decision making and selection	289
8.3.1	Selection of parameters	289
8.3.2	Use of utility analyses	292
8.4	Quality aspects of instruments	294
8.4.1	What is quality?	294
8.4.2	Quality in relation to instruments	295
8.4.3	Reliability theory	297
8.4.4	Achieving high reliability	299
8.4.5	Economic issues	304
8.5	Instrument evaluation	307
8.5.1	Need and purposes of instrument evaluation	307
8.5.2	Procedures for instrument evaluation	308
8.5.3	Suggested test parameters	309
8.6	Installation and commissioning	309
8.6.1	Installation a critical stage	309
8.6.2	The commissioning phase	313
8.6.3	Influence parameters	314
8.6.4	Calibration aspects	315
8.6.5	Measurement assurance planning	316
8.6.6	Management of existing systems	317
	<b>Tutorial examples</b>	<b>318</b>
	<b>References</b>	<b>318</b>
	<b>Index</b>	<b>321</b>