



# Practical Interfacing in the Laboratory

Using a PC for instrumentation, data analysis, and control

Stephen E. Derenzo

CAMBRIDGE

# Contents

<i>Preface</i>	xiii
<i>Acknowledgments</i>	xvii

---

<b>1</b>	<b>Digital tools</b>	<b>1</b>
1.1	Introduction	1
1.2	The microcomputer	2
1.3	Number systems	5
1.4	Digital building blocks	8
1.5	Digital counters/timers	13
1.6	Parallel and serial input/output ports	18
1.7	Digital data-acquisition procedures	29
1.8	Switch debouncing	33
1.9	Digital interfacing standards	35
1.10	Problems	44
1.11	Additional reading	51
	<b>Laboratory exercises</b>	
1.	Introduction to C programming	53
2.	Measuring event times	58
3.	Digital interfacing: switches and lights	66

---

<b>2</b>	<b>Analog tools</b>	<b>75</b>
2.1	Introduction	75
2.2	Operational-amplifier circuits	76
2.3	Op-amp characteristics	85
2.4	Instrumentation and isolation amplifiers	89

---

2.5	Noise sources	94
2.6	Analog filtering	98
2.7	The power amplifier	117
2.8	Problems	118
2.9	Additional reading	127

### Laboratory exercises

4.	Operational-amplifier circuits	128
5.	Instrumentation amplifiers	136
6.	Analog filtering	145

---

## 3 Analog ↔ digital conversion and sampling 153

---

3.1	Introduction	153
3.2	Digital-to-analog converter circuits	153
3.3	Analog-to-digital converter circuits	161
3.4	The sample-and-hold amplifier	173
3.5	Sampling analog waveforms	180
3.6	Frequency aliasing	183
3.7	Available data-acquisition systems	186
3.8	Problems	187
3.9	Additional reading	200

### Laboratory exercises

7.	Introduction to A/D and D/A conversion	201
8.	D/A conversion and waveform generation	206
9.	A/D conversion and periodic sampling	213
10.	Frequency aliasing	221

---

## 4 Sensors and actuators 226

---

4.1	Introduction	226
4.2	Position and angle sensors	228
4.3	Temperature transducers	234
4.4	Strain-sensing elements	253
4.5	Force and pressure transducers	255
4.6	Measuring light	261
4.7	Producing visible light	268

4.8	Ionic potentials	271
4.9	The detection and measurement of ionizing radiation	274
4.10	Measuring time	277
4.11	Problems	278
4.12	Additional reading	298

### Laboratory exercises

11.	Measuring angular position	300
12.	Measuring temperature	305
13.	Measuring strain and force	311
14.	Measuring light with a photodiode	316
15.	The thermoelectric heat pump	322
16.	Electrodes and ionic media	329
17.	The human heart	334
18.	The electromyogram (EMG)	343
19.	The electrooculogram (EOG)	352

## 5 Data analysis and control 360

5.1	Introduction	360
5.2	The Gaussian-error distribution	360
5.3	Student's $t$ test	366
5.4	Least-squares fitting	372
5.5	The chi-squared statistic	375
5.6	Solving nonlinear equations	379
5.7	Monte Carlo simulation	383
5.8	Fourier transforms	385
5.9	Digital filters	415
5.10	Control techniques	419
5.11	Problems	427
5.12	Additional reading	448

### Laboratory exercises

20.	Analog $\leftrightarrow$ digital conversion and least-squares fitting	449
21.	Fast Fourier transforms of sampled data	454
22.	Fast Fourier transforms of the human voice	461
23.	Digital filtering	471
24.	Process compensation using Fourier deconvolution and digital filtering	477
25.	Analog temperature control using a resistive heater	485

26. Temperature control using the computer and a resistive heater	490
27. Temperature control using the computer and a thermoelectric heat pump	497
<b>Appendix A</b> Grounding and shielding	504
A.1 Introduction	504
A.2 Interference noise due to common impedance	504
A.3 Interference noise due to capacitive coupling	505
A.4 General rules to follow	506
<b>Appendix B</b> Experimental uncertainties	508
B.1 Multimeter accuracy	508
B.2 Propagation of random error	508
<b>Appendix C</b> C programming tips	510
C.1 Declare all variables	510
C.2 Arithmetic statements	510
C.3 Conditional tests	511
C.4 Conditional operators	511
C.5 Indexed looping	511
C.6 Bitwise logical operators	512
C.7 Increment and decrement operators	512
C.8 The printf statement	513
C.9 Defining your own functions	513
C.10 "Including" your own functions	514
C.11 Opening and writing to files of arbitrary name	515
C.12 Using library functions	515
C.13 Allocating large storage arrays	516
C.14 General format rules for C programs	516
<b>Appendix D</b> Numerical methods and C functions	517
D.1 Introduction	517
D.2 Fast Fourier transform	517
D.3 Minimization function PARFIT	520
D.4 The uncertainty estimation function VARFIT	529
D.5 Numerical evaluation of functions defined by integrals	542
D.6 Function inversion using Newton's method	549
D.7 Function inversion using quadratic approximation	549
D.8 Random number generator	550
<b>Appendix E</b> Summary of Data Translation DT3010 PCI plug-in card	553
E.1 Introduction	553
E.2 Parallel output	553
E.3 Parallel input	556

E.4	Analog output	556
E.5	Analog input	557
E.6	Using the DT3010 board with the Microsoft visual C++ compiler	557
<b>Appendix F</b>	<b>Using the digital oscilloscope to record waveforms</b>	<b>558</b>
F.1	Introduction	558
F.2	Capturing the waveform	558
F.3	Printing the waveform	558
<b>Appendix G</b>	<b>Electrical hazards and safety</b>	<b>560</b>
G.1	Introduction	560
G.2	Electrical power	561
G.3	The ground fault interrupter circuit	563
G.4	The isolation transformer	564
G.5	Typical accident scenarios	564
G.6	Methods of accident prevention	564
<b>Appendix H</b>	<b>Standard resistor and capacitor values</b>	<b>566</b>
H.1	Standard resistor values and color codes	566
H.2	Standard capacitor values and codes	566
<b>Appendix I</b>	<b>ASCII character codes</b>	<b>569</b>
I.1	ASCII character set codes	569
	<i>Glossary</i>	572
	<i>Index</i>	602