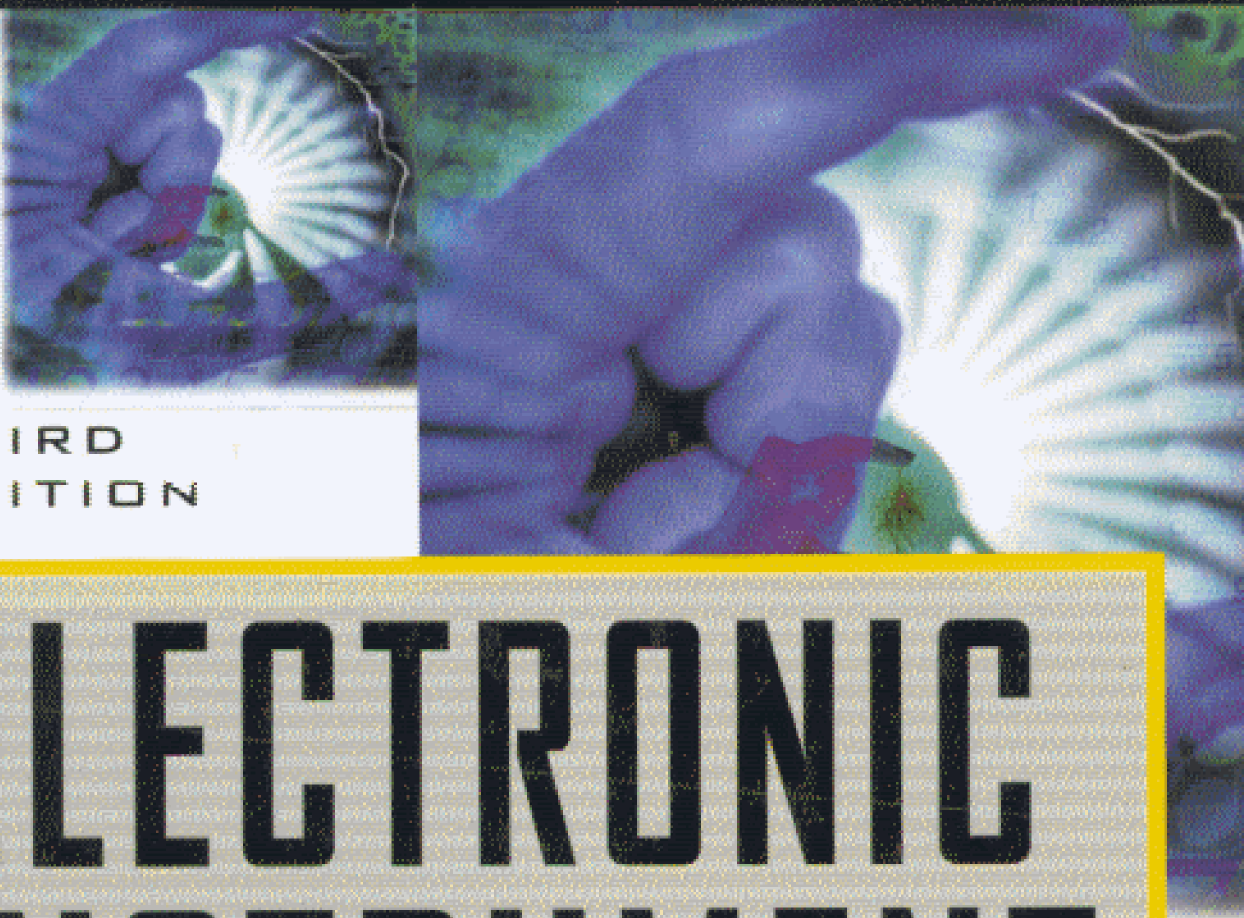
McGRAW-HILL HANDBOOKS



THIRD EDITION

ELECTRONIC INSTRUMENT HANDBOOK

Suranaree University of Technology
31051000655684

CLYDE F. COOMBS, JR.

Contents

Contributors xxi
Foreword by Dr. Frederick E. Terman xxiii
Preface xxv

Part 1 Introduction to Electronic Instruments and Measurements

Chapter 1. Introduction to Electronic Instruments and Measurements ***Bonnie Stahlin*** **1.1**

1.1. Introduction *1.1*
1.2. Instrument Software *1.1*
1.3. Instruments *1.3*
1.4. The Signal Flow of Electronic Instruments *1.7*
1.5. The Instrument Block Diagram *1.14*
1.6. Measurement Systems *1.16*
1.7. Summary *1.25*

Chapter 2. Calibration, Traceability, and Standards ***David R. Workman*** **2.1**

2.1. Metrology and Metrologists *2.1*
2.2. Definitions for Fundamental Calibration Terms *2.1*
2.3. Traceability *2.3*
2.4. Calibration Types *2.4*
2.5. Calibration Requirements *2.5*
2.6. Check Standards and Cross-Checks *2.6*
2.7. Calibration Methodology *2.7*
2.8. Instrument Specifications and Calibration Tests *2.10*
2.9. Calibration Standard Requirements *2.12*
References *2.14*
Bibliography *2.14*

Chapter 3. Basic Electronic Standards ***David R. Workman*** **3.1**

3.1. International System of Measurement Units *3.1*
3.2. Traceability of Standards *3.10*
3.3. Standards Maintained by NIST *3.12*
References *3.13*
Bibliography *3.13*

Chapter 4. Data-Acquisition Systems ***Fred Cruger*** **4.1**

4.1. Introduction to Data-Acquisition Systems *4.1*
4.2. Information Rate and Data Rate *4.6*

4.3. Data and Control Connections *4.9*
4.4. Software Alternatives *4.15*

Chapter 5. Transducers *J. Fleming Dias* 5.1

5.1. Introduction *5.1*
5.2. Transduction Mechanisms and Measurands *5.2*
5.3. Classification of Transducers *5.3*
5.4. Selection of Transducers *5.3*
5.5. Capacitive Transducers *5.5*
5.6. Inductive Transducers *5.8*
5.7. Electromagnetic Transducers *5.10*
5.8. Resistive Transducers *5.10*
5.9. Hall-Effect Transducers *5.19*
5.10. Chemfet Transducers *5.20*
5.11. Piezoelectric Wave-Propagation Transducers *5.22*
5.12. Tunneling Displacement Transducers *5.35*
5.13. Thermodynamic Transducers *5.36*
5.14. Ionization Transducers *5.41*
5.15. Photonic Transducers *5.43*
5.16. Fiber-Optic Transducers *5.51*
References *5.56*

Chapter 6. Analog-to-Digital Converters *John J. Corcoran* 6.1

6.1. Introduction *6.1*
6.2. What Is an Analog-to-Digital Converter? *6.1*
6.3. Types of Analog-to-Digital Converters *6.7*
6.4. Integrating Analog-to-Digital Converters *6.8*
6.5. Parallel Analog-to-Digital Converters *6.12*
6.6. Multistep Analog-to-Digital Converters *6.19*
6.7. Static ADC Errors and Testing Techniques *6.22*
6.8. Dynamic ADC Errors and Testing Techniques *6.27*
References *6.36*

Chapter 7. Signal Sources *Charles Kingsford-Smith* 7.1

7.1. Introduction *7.1*
7.2. Kinds of Signal Waveforms *7.1*
7.3. How Periodic Signals Are Generated *7.8*
7.4. Signal Quality Problems *7.16*

Chapter 8. Microwave Signal Sources *William Heinz* 8.1

8.1. Introduction *8.1*
8.2. Solid-State Sources of Microwave Signals *8.2*
8.3. Control and Modulation of Signal Sources *8.9*
8.4. Frequency Synthesis *8.11*

Chapter 9. Digital Signal Processing *John Guilford* 9.1

9.1. Introduction *9.1*
9.2. Signal Characterization *9.2*

9.3. Signal Representations *9.3*
9.4. Signal Processing *9.5*
9.5. Digital Signal Processing *9.8*
9.6. Digitizing Process *9.12*
9.7. Linear Filters *9.20*
9.8. Changing Sample Rate *9.25*
9.9. Frequency Translation *9.26*
9.10. Other Non-Linear Processing *9.26*
9.11. Fourier Transform *9.27*
9.12. Digital Signal Processing Hardware *9.31*
9.13. Software Implementations *9.36*
9.14. Design of Signal-Processing Algorithms *9.36*
Bibliography *9.37*

Chapter 10. Embedded Computers in Electronic Instruments ***Tim Mikkelsen*** **10.1**

10.1. Introduction *10.1*
10.2. Embedded Computers *10.2*
10.3. Embedded Computer System Hardware *10.5*
10.4. Elements of an Embedded Computer *10.10*
10.5. Physical Form of the Embedded Computer *10.13*
10.6. Architecture of the Embedded Computer Instrument *10.13*
10.7. Embedded Computer System Software *10.15*
10.8. User Interfaces *10.24*
10.9. External Interfaces *10.25*
10.10. Numerical Issues *10.29*
10.11. Instrumentation Calibration and Correction Using Embedded Computers *10.35*
10.12. Using Instruments That Contain Embedded Computers *10.37*

Chapter 11. Power Supplies ***James S. Gallo*** **11.1**

11.1. Function and Types of Power Supplies and Electronic Loads *11.1*
11.2. The Direct-Current Power Supply *11.2*
11.3. The Electronic Load *11.5*
11.4. The Alternating-Current Power Source *11.8*
11.5. General Architecture of the Power-Conversion Instrument *11.9*
11.6. Power Supply Instruments for Specific Applications *11.21*
11.7. Selecting Your Power-Conversion Instrument *11.22*

Chapter 12. Instrument Hardware User Interfaces ***Jan Ryles*** **12.1**

12.1. Introduction *12.1*
12.2. Hardware-User Interface Components *12.1*

Part 2 Current and Voltage Measurement Instruments

Chapter 13. Voltage, Current, and Resistance Measuring Instruments ***Scott Stever*** **13.1**

13.1. Introduction *13.1*
13.2. General Instrument Block Diagram *13.2*
13.3. DC Voltage Measurement Techniques *13.4*

13.4. AC Voltage Measurement Techniques *13.6*
13.5. Current Measurement Techniques *13.11*
13.6. Resistance Measurement Techniques *13.13*
13.7. Sources of Measurement Error *13.16*
13.8. Interpreting Specifications *13.29*
13.9. Considerations When Selecting a Meter *13.34*

Chapter 14. Oscilloscopes ***Alan J. De Vilbiss*** **14.1**

14.1. Introduction *14.1*
14.2. General Oscilloscopes Concepts *14.3*
14.3. Vertical Amplifier *14.8*
14.4. Horizontal or Time Base and Trigger *14.21*
14.5. The Analog Oscilloscope *14.32*
14.6. The Digital Oscilloscope *14.47*
14.7. Comparing Analog and Digital Oscilloscopes *14.63*
14.8. Oscilloscope Probes *14.64*
14.9. How to Buy an Oscilloscope *14.71*

Chapter 15. Power Measurements ***Ronald E. Pratt*** **15.1**

15.1. Introduction *15.1*
15.2. Basic Power Definitions *15.1*
15.3. Transmission-Type Power Measurements *15.3*
15.4. Absorption-Type Power Measurements *15.6*
15.5. Thermistor Sensors and Meters *15.7*
15.6. Thermocouple Power Meters *15.10*
15.7. Diode Power Sensors *15.13*
15.8. Peak Power Measurements *15.16*
15.9. Effect of Multiple Reflections *15.16*
15.10. Specifications *15.18*
15.11. Calibration *15.19*

Part 3 Signal and Waveform Generation Instruments

Chapter 16. Oscillators, Function Generators, Frequency and Waveform Synthesizers ***Charles Kingsford-Smith*** **16.1**

16.1. Introduction *16.1*
16.2. Sine-Wave Oscillators *16.1*
16.3. Function Generators *16.5*
16.4. Frequency Synthesizers *16.11*
16.5. Arbitrary Waveform Synthesizers *16.22*

Chapter 17. Pulse Generators ***Andreas Pfaff*** **17.1**

17.1. Introduction *17.1*
17.2. Pulse Generator Basics *17.3*
17.3. Special Pulse Generators *17.5*
17.4. Applications *17.7*
17.5. Important Specifications *17.11*

Chapter 18. Microwave Signal Generators ***William Heinz*** **18.1**

18.1. Introduction *18.1*
18.2. Types of Signal Generators *18.2*
18.3. Types of Modulation *18.3*
18.4. Microwave Signal Generator Architectures *18.7*
18.5. Basic Microwave Signal Generator Specifications *18.18*

Part 4 Frequency and Time Measurement Instruments

Chapter 19. Electronic Counters and Frequency and Time Interval Analyzers ***Rex Chappell*** **19.1**

19.1. Introduction *19.1*
19.2. Instrument Types and Application Overview *19.1*
19.3. Basic Instrument Architectures and Operation *19.8*
19.4. Specifications and Significance *19.19*

Chapter 20. Precision Time and Frequency Sources ***Leonard S. Cutler and John A. Kusters*** **20.1**

20.1. Requirements and Definitions *20.1*
20.2. Frequency Standards *20.5*
20.3. Primary Frequency Standards *20.6*
20.4. Secondary Standards *20.14*
20.5. Comparison of Standards *20.18*
20.6. Time Standards *20.19*
20.7. Ensembles of Time and Frequency Standards *20.24*
20.8. Precision Time and Frequency Comparisons *20.26*

Chapter 21. Spectrum Analyzers ***Alan W. Schmidt*** **21.1**

21.1. Introduction *21.1*
21.2. Basic Spectrum Analyzer Operation *21.4*
21.3. Swept Superheterodyne Spectrum Analyzer *21.4*
21.4. Auxiliary Equipment *21.15*

Part 5 Lightwave Test and Measurement Instruments

Chapter 22. Lightwave Signal Sources ***Waguih Ishak*** **22.1**

22.1. Introduction: Fiber-Optic Communications Systems *22.1*
22.2. External Cavity Laser Fundamentals *22.5*
22.3. Design Challenges *22.8*
22.4. Specifications *22.9*

Chapter 23. Lightwave Signal Analysis ***Waguih Ishak*** **23.1**

23.1. Introduction *23.1*
23.2. Light Sources *23.1*

23.3. Optical Power Meters *23.8*
23.4. Lightwave Signal Analyzers *23.10*
23.5. Optical Spectrum Analyzers *23.12*
23.6. Linewidth Measurements *23.20*
23.7. Lightwave Polarization Analyzers *23.21*

Chapter 24. Lightwave Component Analyzers ***Waguih Ishak*** **24.1**

24.1. Introduction *24.1*
24.2. Modulation Domain Component Analyzers *24.2*
24.3. Wavelength Domain Component Analyzers *24.8*
24.4. Reflection-Based Component Analyzers *24.10*

Chapter 25. Optical Time Domain Reflectometers ***Waguih Ishak*** **25.1**

25.1. Introduction *25.1*
25.2. OTDR Fundamentals *25.1*
25.3. The Complementary Correlation OTDR *25.6*
25.4. OTDR Applications *25.10*
25.5. OTDR Specifications *25.10*

Part 6 Circuit Element Measurement Instruments

Chapter 26. Impedance Measurement Instruments ***Yoh Narimatsu*** **26.1**

26.1. Introduction to Impedance Measurements *26.1*
26.2. Basic Definitions *26.1*
26.3. Characteristics of Electronic Components *26.5*
26.4. Impedance Measuring Techniques *26.8*
26.5. Connection and Guarding *26.12*
26.6. Accuracy Considerations *26.18*
26.7. Impedance Measuring Instruments *26.20*
Bibliography *26.34*

Chapter 27. Semiconductor Test Instrumentation ***James L. Hook*** **27.1**

27.1. Introduction to Semiconductor Test Instrumentation *27.1*
27.2. Electronic Instrumentation Unique to Semiconductor Testing *27.5*
27.3. Semiconductor Test System Architecture Overview *27.22*
27.4. Common Semiconductor Test System Configurations *27.25*
27.5. Continuing Trends in Semiconductor Test Instruments and Systems *27.29*

Chapter 28. Network Analyzers ***Daniel R. Harkins*** **28.1**

28.1. Introduction *28.1*
28.2. Component Characteristics *28.2*
28.3. Network Analysis System Elements *28.4*
28.4. Measurement Accuracy *28.9*
28.5. Scalar Network Analysis *28.12*
28.6. Vector Network Analysis *28.17*

Part 7 Digital Domain Instruments

Chapter 29. Logic Analyzers ***Steve Warntjes*** **29.1**

29.1. Introduction to the Digital Domain *29.1*
29.2. Basic Operation *29.3*
29.3. Using the Key Functions *29.10*
29.4. Instrument Specifications/Key Features *29.21*
29.5. Getting the Most from a Logic Analyzer *29.28*

Chapter 30. Protocol Analyzers ***Steve Witt*** **30.1**

30.1. Introduction *30.1*
30.2. Protocol Analyzers *30.7*
30.3. Protocol Analysis *30.12*
30.4. Protocol Analyzer Implementations *30.26*
30.5. Basic Protocol Analyzer Architectures *30.32*
30.6. Protocol Analyzer Selection Criteria *30.36*

Chapter 31. Bit Error Rate Measuring Instruments: Pattern Generators and Error Detectors ***Hugh Walker*** **31.1**

31.1. Introduction *31.1*
31.2. Sources of Errors *31.1*
31.3. Error Measurements *31.5*
31.4. Bit Error Rate (BER) Instrument Architecture *31.18*
31.5. Bit Error Rate Measuring Instrument Specifications *31.23*

Part 8 Microwave Passive Devices

Chapter 32. Microwave Passive Devices ***Frank K. David*** **32.1**

32.1. Introduction *32.1*
32.2. Coaxial Transmission Lines *32.1*
32.3. Coaxial Passive Devices *32.4*
32.4. Planar Transmission Lines *32.12*
32.5. Planar Passive Devices *32.15*
32.6. Waveguides *32.21*
32.7. Waveguide Passive Devices *32.27*

Part 9 Using Electronic Instruments

Chapter 33. Impedance Considerations ***K. D. Baker and D. A. Burt*** **33.1**

33.1. Introduction *33.1*
33.2. The Impedance Concept *33.2*
33.3. Input and Output Impedance *33.9*
33.4. Effects of Instrument Input and Output Impedances on Measurements *33.12*
33.5. Impedance Matching *33.19*
33.6. Effects of Impedance Mismatch *33.21*

Chapter 34. Electrical Interference ***D. A. Burt and K. D. Baker*** **34.1**

34.1. Introduction *34.1*
34.2. Interference and Noise Terminology *34.1*
34.3. Instrument Noise *34.2*
34.4. Radiated Interference *34.3*
34.5. Shielding *34.6*
34.6. Conducted Interference *34.9*
34.7. Common-Mode Interference *34.10*
34.8. Crosstalk *34.17*
34.9. Contact Potential *34.18*
34.10. Instrument Interconnections *34.19*
34.11. General Characteristics and Source of Interference *34.20*
34.12. Specific Interference-Source-Reduction Techniques *34.21*
34.13. Summary *34.23*

Chapter 35. Electrical Grounding ***D. A. Burt and K. D. Baker*** **35.1**

35.1. Introduction *35.1*
35.2. AC Power Grounds *35.2*
35.3. Instrument Power Input *35.2*
35.4. Instrument Grounds *35.3*
35.5. Summary *35.12*

Chapter 36. Distributed Parameters and Component Considerations ***K. D. Baker and D. A. Burt*** **36.1**

36.1. Introduction *36.1*
36.2. DC Resistance *36.1*
36.3. AC Resistance *36.3*
36.4. Leakages *36.5*
36.5. Component Stray Parameters *36.10*

Chapter 37. Digital Interface Issues ***D. A. Burt and K. D. Baker*** **37.1**

37.1. Introduction *37.1*
37.2. Asynchronous Systems *37.1*
37.3. Synchronous Systems *37.2*
37.4. Interface Drivers *37.3*
37.5. Addressing *37.4*
37.6. Data Compression *37.4*
37.7. Operational Concerns *37.5*
37.8. Interface Standards *37.6*

Part 10 Instruments in Systems

Chapter 38. Instrument Systems ***James M. McGillivary*** **38.1**

38.1. Introduction *38.1*
38.2. Instrument System Hardware Architecture *38.1*
38.3. Instruments *38.1*
38.4. Switching System *38.3*
38.5. Computer Controller *38.6*

38.6. Device Under Test *38.7*
38.7. Instrument-To-Controller Interconnect *38.7*
38.8. Power Conditioning/Distribution Unit *38.10*
38.9. System Resource Interface *38.11*
38.10. Signal Cabling *38.15*
38.11. Putting It All Together: The Rack Layout *38.20*
38.12. Software *38.23*
38.13. Applications of Instrument Systems *38.24*
References *38.28*

Chapter 39. Switches in Automated Test Systems ***Calvin Erickson*** **39.1**

39.1. Introduction *39.1*
39.2. Switch Topologies *39.12*
39.3. Switch-Element Technologies *39.6*
39.4. Reducing Electronic Noise in Switch Network Design *39.7*
39.5. Integration Procedure for Test System Switching *39.10*

Chapter 40. Standards-Based Modular Instruments ***Dave Richey*** **40.1**

40.1. Overview of Modular Instruments *40.1*
40.2. Elements of Modular Instruments *40.5*
40.3. The System Backplane *40.5*
40.4. Form Factors *40.7*
40.5. VME (VMEbus) Specifications *40.8*
40.6. VXI (VMEbus Extensions for Instrumentation) *40.11*
40.7. VXI Standard Specifications *40.18*
40.8. Personal Computer Plug-Ins (PCPIs) *40.20*
40.9. CompactPCI *40.22*

Part 11 Software and Connectivity for Instrumentation

Chapter 41. Software and Instrumentation ***Phil Christ and Bonnie Stahlin*** **41.1**

41.1. Software Role in Instrumentation *41.1*
41.2. Software Used by Instrumentation *41.4*
41.3. Connecting Models: Instruments and Software *41.9*
41.4. Internet "Client-Server" Connection *41.15*

Chapter 42. Networked Connectivity for Instruments ***Tim Tillson*** **42.1**

42.1. Instrument Models *42.2*
42.2. Introduction to Computer Networks *42.3*
42.3. Network Protocols and Software Standards *42.7*
42.4. Network Connectivity Models *42.10*

Chapter 43. Computer Connectivity for Instruments ***Joseph E. Mueller*** **43.1**

43.1. Introduction *43.1*
43.2. Physical Input/Output Layer *43.5*

43.3. Network Protocols for Test and Measurement *43.12*
43.4. Messages Sent Between Computers and Instruments *43.12*
43.5. I/O Libraries *43.14*
43.6. Instrument Drivers *43.16*
43.7. Performance and System Throughput *43.18*

Chapter 44. Graphical User Interfaces for Instruments ***Jan Ryles*** **44.1**

44.1. Introduction *44.1*
44.2. Introduction to Graphical User Interfaces *44.2*
44.3. Instrument Configurations *44.2*
44.4. Changes in User's Overall Experience *44.6*
44.5. Drivers for the Evolution of Graphical User Interfaces *44.8*
44.6. The Evolution of Instrument User Interfaces *44.10*
44.7. Evaluating the Instrument User Interface *44.14*
44.8. Evaluation Checklist *44.19*

Chapter 45. Virtual Instruments ***Darren Kwock*** **45.1**

45.1. Introduction *45.1*
45.2. Instrument Models *45.2*
45.3. Instrumentation Components *45.6*
45.4. Virtual Instrument Classes *45.12*
45.5. Implementing Virtual Instrument Systems *45.15*
45.6. Computer Industry Impact on Virtual Instrumentation *45.22*
45.7. Summary *45.24*

Part 12 Distributed and Networked Instrumentation

Chapter 46. Distributed Measurement Systems ***Geri Georg*** **46.1**

46.1. Introduction to Distributed Measurement Systems *46.1*
46.2. Distributed Computation System Characteristics *46.2*
46.3. Distributed Measurement Systems *46.4*
46.4. Instrument/Computer Communication Standards *46.7*
46.5. System Planning and Development *46.8*
46.6. Typical Distributed Measurement System Topology *46.8*
46.7. Distributable Functions *46.17*
46.8. Reasons for Distribution *46.19*
46.9. Software for Distributed Measurement Systems *46.20*
46.10. Problem Domain and Information Model *46.22*
46.11. Developing Distributed Measurement Systems *46.28*

Chapter 47. Smart Transducers (Sensors or Actuators), Interfaces, and Networking ***Kang Lee*** **47.1**

47.1. Introduction *47.1*
47.2. The Evolution of Smart Transducers *47.7*
47.3. Elements of a Smart Transducer *47.10*
47.4. Interfaces and Networks for Smart Transducers *47.12*

47.5. Software for Smart Transducers *47.17*
47.6. A Smart Transducer Interface Standard: IEEE 1451 *47.18*
47.7. Advantages of Networking Smart Transducers *47.24*
References *47.25*

Acronyms and Abbreviations A.1
Index I.1