

PRINCIPLES  
AND  
APPLICATIONS  
SECOND EDITION

■  
John Webb



**P**ROGRAMMABLE

**L**OGIC

**C**ONTROLLERS



9761415

# Programmable Logic Controllers

---

**Principles and Applications**

**Second Edition**



---

**John W. Webb**

**Northcentral Technical College  
Wausau, Wisconsin**

---



E9761415

**Merrill, an imprint of  
Macmillan Publishing Company  
New York**

**Maxwell Macmillan Canada  
Toronto**

**Maxwell Macmillan International  
New York □ Oxford □ Singapore □ Sydney**

Cover photo courtesy of Allen-Bradley

Editor: Dave Garza

Production Editor: Rex Davidson

Art Coordinator: Vincent A. Smith

Cover Designer: Robert Vega

Production Buyer: Pamela D. Bennett

This book was set in Times Roman by Bi-Comp, Inc. and was printed and bound by Book Press, Inc., a Quebecor America Book Group Company.

The cover was printed by Lehigh Press, Inc.

Copyright © 1992 by Macmillan Publishing Company, a division of Macmillan, Inc. Merrill is an imprint of Macmillan Publishing Company.

Printed in the United States of America

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the Publisher.

First edition, entitled *Programmable Controllers: Principles and Applications*, copyright © 1988 by Merrill Publishing Company.

Macmillan Publishing Company, 866 Third Avenue, New York, NY 10022

Macmillan Publishing Company is part of the  
Maxwell Communication Group of Companies.

Maxwell Macmillan Canada, Inc.  
1200 Eglington Avenue East, Suite 200  
Don Mills, Ontario M3C 3N1

Library of Congress Cataloging-in-Publication Data  
Webb, John W.

Programmable logic controllers : principles and applications /  
John W. Webb. -- 2nd ed.

p. cm.

Rev. ed. of: Programmable controllers. 1988.

Includes bibliographical references and index.

ISBN 0-02-424970-X

1. Programmable controllers. I. Webb, John W. Programmable  
controllers. II. Title.

TJ223.P76W43 1992

629.8'95--dc20

91-14613  
CIP

Printing: 2 3 4 5 6 7 8 9 Year: 3 4 5

---

---

# Preface

The market for programmable logic controllers is projected to grow to hundreds of millions of dollars a year in the United States. The need for training in PLC application is increasing at all levels, in technical schools, colleges, and industry. The purpose of this text is to provide PLC training in all of these educational areas.

The second edition has been revised to include a number of new features:

- “PC” has been changed to “PLC” throughout the book where we mean Programmable Logic Controller. “PC” can stand for Personal Computer, which can create some confusion in terms.
- The book has been divided into seven sections.
- Updated equipment illustrations are included.
- Alternate programming formats have been added to make the book more generic.
- To get into actual PLC programming earlier in the book, chapter order has been revised.
- Newly developed functions have been added in appropriate chapters.
- Simpler examples have been added at the beginning of many chapters to ease the student into the subjects.
- Added exercises are included in some chapters.
- Explanations have been added as to where a function can be used to advantage (for an example, see the chapter on Matrices).

- Two new chapters have been added:  
Chapter 20: Networking PLCs and Chapter 21: PID Control.
- The Bibliography, Glossary, and Index have been appropriately revised.

Each chapter includes learning objectives, an introduction, explanations and examples, and questions. There is a glossary and bibliography at the end. A solutions manual, which includes answers to all chapter questions, is available. Unlike manufacturers' manuals and most PLC texts, this book includes many programming examples and exercise problems for each type of PLC function. It is also generic, to apply to many different PLC models.

Another feature of this book is that it is possible to use a portion of each chapter, depending on the depth of training required. For example, chapter 14 covers the PLC Move functions; for a course in basic functions, only Section A on the Move function need be covered. Chapter questions are arranged so that only the applicable sections (the first series of questions) need be used when a function does not have to be covered in depth. For more extensive training on a function, the other portions of a chapter may be covered as required.

For a longer course, all chapters in the text could be covered. For a shorter course, only selected chapters could be used. Depending on students' backgrounds, chapters could be included or omitted. In some cases the sequential order may not follow the order in the book.

The text is divided into seven sections. The chart shows which sections would probably be of interest in the listed training situations. Certain sections are of high interest (H) for a given audience, others of medium interest (M), and some of low interest (L). Of course, each training situation calls for a varying amount of time and emphasis on each section and chapter. Also, individual chapters can be covered completely or lightly, depending on the students' background.

	Section of this Book						
	A	B	C	D	E	F	G
Limited Length PLC School	H	H	H	M	L	L	L
In-house Manufacturer's School	H	H	H	H	M	L	L
Electrical Trades	H	H	H	M	L	L	H
Vocational Electrical/Mechanical Programs	H	H	H	H	L	L	L
Associate Degree, Electronics Related	H	H	H	H	M	L	L
Associate Degree, Electromechanical/Robotics	H	H	H	H	H	H	M
Technology, Four-year School	H	H	H	H	H	H	H
Engineering School	H	H	H	H	H	H	H

## Acknowledgments

I would like to thank the reviewers for their helpful comments:

Roger Bertrand, Central Maine Technical Institute; Ken Edwards, International Brotherhood of Electrical Workers; Phil Henning, Williamsport Community College; Thomas Kissell, Terra Technical College; E.W. McCullough, Rowan Technical College; William G. Pfautz, De Kalb Area Technical School; Terry S. Taebel; and Stephen Tubbs, Pennsylvania State University—McKeesport. I also want to thank the following companies and people for their support and cooperation in preparing *Programmable Logic Controllers*: Giddings and Lewis Electronics; Westinghouse Electric, Numa Logic; Texas Instruments, Inc.; General Electric; Eaton Corp, Cutler Hammer Products; TII Robotics Systems, Division of TII Robotic Systems, Inc.; Northcentral Technical College, Wausau, Wisconsin; L and S Electric, Schofield, Wisconsin; Amatrol; Best Power Technology; ABB Robotics; Bussmann Division/Cooper Industries; Square D Company; Paula Webb Clark; and Thelma Webb.

### NOTICE TO THE READER

The publisher and the author(s) do not warrant or guarantee any of the products and/or equipment described herein nor has the publisher or the author(s) made any independent analysis in connection with any of the products, equipment, or information used herein. The reader is directed to the manufacturer for any warranty or guarantee for any claim, loss, damages, costs, or expense, arising out of or incurred by the reader in connection with the use or operation of the products and/or equipment.

The reader is expressly advised to adopt all safety precautions that might be indicated by the activities and experiments described herein. The reader assumes all risks in connection with such instructions.

*To my wife, Thelma*



## **MERRILL'S INTERNATIONAL SERIES IN ENGINEERING TECHNOLOGY**

### **ADAMSON**

*Applied Pascal for Technology*, 0-675-20771-1  
*The Complete Dictionary of Electronics*, 0-02-300820-2  
*Microcomputer Repair*, 0-02-300825-3  
*Structured BASIC Applied to Technology*,  
0-675-20772-X

### **ANTONAKOS**

*Structured C for Technology*, 0-675-20993-5  
*Structured C for Technology (w/ disks)*, 0-675-21289-8  
*The 68000 Microprocessor: Hardware and Software  
Principles and Applications*, 0-675-21043-7

### **ASSER/STIGLIANO/ BAHRENBURG**

*Microcomputer Servicing: Practical Systems and Trou-  
bleshooting*, 0-675-20907-2  
*Microcomputer Theory and Servicing*, 0-675-20659-6  
*Lab Manual to accompany Microcomputer Theory and  
Servicing*, 0-675-21109-3

### **ASTON**

*Principles of Biomedical Instrumentation and Measure-  
ment*, 0-675-20943-9

### **BATESON**

*Introduction to Control System Technology, Third Edi-  
tion*, 0-675-21010-0

### **BEACH/JUSTICE BERLIN**

*DC/AC Circuit Essentials*, 0-675-20193-4  
*Experiments in Electronic Devices to accompany  
Floyd's Electronic Devices and Electronic Devices:  
Electron Flow Version, Third Edition*,  
0-02-308422-7

### **BERLIN/GETZ**

*The Illustrated Electronics Dictionary*, 0-675-20451-8  
*Experiments in Instrumentation and Measurement*,  
0-675-20450-X

*Fundamentals of Operational Amplifiers and Linear  
Integrated Circuits*, 0-675-21002-X  
*Principles of Electronic Instrumentation and Measure-  
ment*, 0-675-20449-6

### **BERUBE**

*Electronic Devices and Circuits Using MICRO-CAP II*,  
0-02-309160-6

- BOGART** *Electronic Devices and Circuits, Second Edition, 0-675-21150-6*
- BOGART/BROWN** *Experiments in Electronic Devices and Circuits, Second Edition, 0-675-21151-4*
- BOYLESTAD** *DC/AC: The Basics, 0-675-20918-8*  
*Introductory Circuit Analysis, Sixth Edition, 0-675-21181-6*
- BOYLESTAD/KOUSOUROU** *Experiments in Circuit Analysis, Sixth Edition, 0-675-21182-4*  
*Experiments in DC/AC Basics, 0-675-21131-X*
- BREY** *Microprocessors and Peripherals: Hardware, Software, Interfacing, and Applications, Second Edition, 0-675-20884-X*  
*The Intel Microprocessors—8086/8088, 80186, 80286, 80386, and 80486—Architecture, Programming, and Interfacing, Second Edition, 0-675-21309-6*  
*Lab Manual to accompany Electronic Communication Techniques, Second Edition, 0-675-21257-X*
- BROBERG** *Digital Experiments: Emphasizing Systems and Design, Second Edition, 0-675-21180-8*  
*Experiments in Electric Circuits Fundamentals, Second Edition, 0-675-21409-2*  
*Experiments in Electronics Fundamentals: Circuits, Devices and Applications, Second Edition, 0-675-21407-6*
- BUCHLA** *Applied Electronic Instrumentation and Measurement, 0-675-21162-X*  
*Circuit Modeling: Exercises and Software, Second Edition, 0-675-21152-2*
- BUCHLA/McLACHLAN** *Introduction to VersaCAD, 0-675-21164-6*
- CICCARELLI** *Digital Experiments: Emphasizing Troubleshooting, Second Edition, 0-675-21196-4*
- COOPER** *Getting a Job: Resume Writing, Job Application Letters, and Interview Strategies, 0-675-20917-X*
- COX** *Technical Mathematics, 0-675-20338-4*  
*Technical Mathematics with Calculus, 0-675-20965-X*  
*Study Guide to Accompany Technical Mathematics, 0-675-20966-8*  
*Study Guide to Accompany Technical Mathematics with Calculus, 0-675-20964-1*
- CROFT** *Experiments in 8085 Microprocessor Programming and Interfacing, 0-675-20663-4*
- DAVIS** *Digital Fundamentals, Fourth Edition, 0-675-21217-0*  
*Electric Circuits Fundamentals, Second Edition, 0-675-21408-4*
- DELKER**
- FLOYD**

	<i>Electronic Devices, Third Edition, 0-675-22170-6</i>
	<i>Electronic Devices: Electron Flow Version, 0-02-338540-5</i>
	<i>Electronics Fundamentals: Circuits, Devices, and Applications, Second Edition, 0-675-21310-X</i>
	<i>Fundamentals of Linear Circuits, 0-02-338481-6</i>
	<i>Principles of Electric Circuits, Electron Flow Version, Second Edition, 0-675-21292-8</i>
	<i>Principles of Electric Circuits, Third Edition, 0-675-21062-3</i>
<b>FULLER</b>	<i>Robotics: Introduction, Programming, and Projects, 0-675-21078-X</i>
<b>GAONKAR</b>	<i>Microprocessor Architecture, Programming, and Applications with the 8085/8080A, Second Edition, 0-675-20675-8</i>
	<i>The Z80 Microprocessor: Architecture, Interfacing, Programming, and Design, 0-675-20540-9</i>
<b>GILLIES</b>	<i>Instrumentation and Measurements for Electronic Technicians, 0-675-20432-1</i>
<b>GOETSCH</b>	<i>Industrial Supervision: In the Age of High Technology, 0-675-22137-4</i>
<b>GOETSCH/RICKMAN</b>	<i>Computer-Aided Drafting with AutoCAD, 0-675-20915-3</i>
<b>GOODY</b>	<i>Programming and Interfacing the 8086/8088 Microprocessor, 0-675-21312-6</i>
<b>HUBERT</b>	<i>Electric Machines: Theory, Operation, Applications, Adjustment, and Control, 0-675-21136-0</i>
<b>HUMPHRIES</b>	<i>Motors and Controls, 0-675-20235-3</i>
<b>HUTCHINS</b>	<i>Introduction to Quality: Management, Assurance and Control, 0-675-20896-3</i>
<b>KEOWN</b>	<i>PSpice and Circuit Analysis, 0-675-22135-8</i>
<b>KEYSER</b>	<i>Materials Science in Engineering, Fourth Edition, 0-675-20401-1</i>
<b>KIRKPATRICK</b>	<i>The AutoCAD Book: Drawing, Modeling and Applications, Second Edition, 0-675-22288-5</i>
	<i>Industrial Blueprint Reading and Sketching, 0-675-20617-0</i>
<b>KRAUT</b>	<i>Fluid Mechanics for Technicians, 0-675-21330-4</i>
<b>KULATHINAL</b>	<i>Transform Analysis and Electronic Networks with Applications, 0-675-20765-7</i>
<b>LAMIT/LLOYD</b>	<i>Drafting for Electronics, 0-675-20200-0</i>
<b>LAMIT/WAHLER/HIGGINS</b>	<i>Workbook in Drafting for Electronics, 0-675-20417-8</i>
<b>LAMIT/PAIGE</b>	<i>Computer-Aided Design and Drafting, 0-675-20475-5</i>
<b>LAVIANA</b>	<i>Basic Computer Numerical Programming, Second Edition, 0-675-21298-7</i>
<b>MacKENZIE</b>	<i>The 8051 Microcontroller, 0-02-373650-X</i>

**MARUGGI**

*Technical Graphics: Electronics Worktext, Second Edition, 0-675-21378-9*

*The Technology of Drafting, 0-675-20762-2*

*Workbook for the Technology of Drafting, 0-675-21234-0*

**McCALLA  
McINTYRE**

*Digital Logic and Computer Design, 0-675-21170-0*  
*Study Guide to accompany Electronic Devices, Third Edition, and Electronic Devices, Electron Flow Version, 0-02-379296-5*

*Study Guide to accompany Electronics Fundamentals, Second Edition, 0-675-21406-8*

**MILLER**

*The 68000 Microprocessor Family: Architecture, Programming, and Applications, Second Edition, 0-02-381560-4*

**MONACO**

*Essential Mathematics for Electronics Technicians, 0-675-21172-7*

*Introduction to Microwave Technology, 0-675-21030-5*

*Laboratory Activities in Microwave Technology, 0-675-21031-3*

*Preparing for the FCC General Radiotelephone Operator's License Examination, 0-675-21313-4*

*Student Resource Manual to accompany Essential Mathematics for Electronics Technicians, 0-675-21173-5*

**MONSSEN  
MOTT**

*PSpice with Circuit Analysis, 0-675-21376-2*

*Applied Fluid Mechanics, Third Edition, 0-675-21026-7*

*Machine Elements in Mechanical Design, Second Edition, 0-675-22289-3*

**NASHELSKY/BOYLESTAD  
PANARES**

*BASIC Applied to Circuit Analysis, 0-675-20161-6*

*A Handbook of English for Technical Students, 0-675-20650-2*

**PFEIFFER**

*Proposal Writing: The Art of Friendly Persuasion, 0-675-20988-9*

*Technical Writing: A Practical Approach, 0-675-21221-9*

*Introduction to Engineering Technology, 0-675-21003-8*

*The 6800 Microprocessor, 0-675-20515-8*

*Digital Electronics Through Project Analysis, 0-675-21141-7*

*Electronic Project Design and Fabrication, Second Edition, 0-02-399230-1*

*Laboratory Manual for Digital Electronics Through Project Analysis, 0-675-21254-5*

**ROLLE**

*Thermodynamics and Heat Power, Third Edition, 0-675-21016-X*

**ROSENBLATT/FRIEDMAN**

*Direct and Alternating Current Machinery, Second Edition, 0-675-20160-8*



- ROZE** *Technical Communication: The Practical Craft*, 0-675-20641-3
- SCHOENBECK** *Electronic Communications: Modulation and Transmission, Second Edition*, 0-675-21311-8  
*Laboratory Manual to Accompany Electronic Communications*, 0-675-21397-5
- SCHWARTZ** *Survey of Electronics, Third Edition*, 0-675-20162-4
- SELL** *Basic Technical Drawing*, 0-675-21001-1
- SMITH** *Statistical Process Control and Quality Improvement*, 0-675-21160-3
- SORAK** *Linear Integrated Circuits: Laboratory Experiments*, 0-675-20661-8
- SPIEGEL/LIMBRUNNER** *Applied Statics and Strength of Materials*, 0-675-21123-9
- STANLEY, B.H.** *Experiments in Electric Circuits, Third Edition*, 0-675-21088-7
- STANLEY, W.D.** *Operational Amplifiers with Linear Integrated Circuits, Second Edition*, 0-675-20660-X
- SUBBARAO** *16/32-Bit Microprocessors: 68000/68010/68020 Software, Hardware, and Design Applications*, 0-675-21119-0
- TOCCI** *Electronic Devices: Conventional Flow Version, Third Edition*, 0-675-20063-6  
*Fundamentals of Pulse and Digital Circuits, Third Edition*, 0-675-20033-4  
*Introduction to Electric Circuit Analysis, Second Edition*, 0-675-20002-4  
*Fundamentals of Electronic Devices, Fourth Edition*, 0-675-21259-6
- TOCCI/OLIVER** *Programmable Logic Controllers: Principles and Applications, Second Edition*, 0-02-424970-X
- WEBB** *Industrial Control Electronics*, 0-675-20897-1
- WEBB/GRESHOCK** *Basic Technical Writing, Sixth Edition*, 0-675-21256-1
- WEISMAN** *Modern Hydraulics: The Basics at Work*, 0-675-20987-0
- WOLANSKY/AKERS** *Statics and Strength of Materials: A Parallel Approach*, 0-675-20622-7
- WOLF**

---

---

# Contents

---

## SECTION A HARDWARE 1

---

### **1 Introduction 3**

Definition of a Programmable Logic Controller, 4 □ Evolution to the Present PLC, 4 □ Advantages of the PLC, 5 □ Disadvantages of the PLC, 7 □ Knowledge Level for PLC Programming, 7

### **2 PLC System Description 9**

Introduction, 10 □ The Overall System, 10 □ The Central Processing Unit, 11 □ The Program/Monitor, 13 □ Input and Output Modules, 15 □ Remote Location to Input/Output Modules, 19 □ Discrete and Analog Modules, 20 □ Printers, 20 □ Program Recording Devices, 21 □ Baud Rate Setting, 22

### **3 Internal Operation of the CPU and I/O Modules 25**

Introduction, 26 □ The Central Processing Unit Operation, 26 □ Other IC Chips Used in PLC Central Processing Units, 27 □ Memory Capacity, 29

- Power Supplies, 29   □ Fixed and Alterable Memory, 31   □ The Processor, 32   □ Input Modules, 34   □ Output Modules, 35
- 

## **SECTION B**

### **BASIC PROGRAMMING   37**

---

#### **4            General Programming Procedures   39**

Introduction, 40   □ Typical Keyboard Layouts, 40   □ Programming Formats, 41   □ Proper Construction of PLC Ladder Diagrams, 42   □ Process Scanning Considerations, 44   □ PLC Operational Faults, 45   □ Fail-Safe Circuits, 46

#### **5            Programming On-Off Inputs to Produce On-Off Outputs   49**

Introduction, 50   □ Inputs/Contacts, 50   □ Outputs/Coils, 52   □ Operational Procedures, 54   □ Contact and Coil Programming Examples, 56   □ Industrial Process Example, 62

#### **6            Auxiliary Commands and Functions   69**

Introduction, 70   □ MONITOR Mode—Ladder Diagrams, 70   □ The FORCE Mode, 72   □ Printing Ladder Diagrams, 74

---

## **SECTION C**

### **BASIC FUNCTIONS   79**

---

#### **7            Creating a Ladder Diagram for a Process Problem   81**

Introduction, 82   □ Ladder Diagrams and Sequence Listings, 82   □ Large Circuit Construction Planning Steps, 86   □ Chapter Example—The Nine Steps, 86

#### **8            Registers and Addresses   93**

Introduction, 94   □ General Characteristics of Registers, 94   □ Register Descriptions, 95

#### **9            Timers   99**

Introduction, 100   □ The Basic PLC Timer Function, 100   □ Examples of Major Types of Timer Functions, 102   □ Examples of Timer Functions, 104   □ An Industrial Process Timing Problem, 113

---

**10 Counters 119**

Introduction, 120 □ The Basic PLC Counter Function, 120 □ Chapter Examples, 121 □ Programs with Both a Counter and a Timer, 124

---

**SECTION D  
INTERMEDIATE FUNCTIONS 129**

---

**11 Arithmetic Functions 131**

Introduction, 132 □ ADDITION, 132 □ SUBTRACTION, 134 □ The Repetitive Clock, 136 □ MULTIPLICATION, 140 □ SQUARING, 141 □ DIVISION, 141 □ SQUARE ROOT, 143 □ DOUBLE PRECISION, 143

**12 Number Comparison Functions 147**

Introduction, 148 □ The Six COMPARISON Functions, 148 □ The General COMPARISON Function, 149 □ Chapter Examples, 150

**13 The SKIP and MASTER CONTROL RELAY Functions 157**

Introduction, 158 □ The SKIP Function, 158 □ The MASTER CONTROL RELAY Function, 163 □ The JUMP Function, 165

**14 Data Move Systems 169**

Introduction, 170 □ The MOVE Function, 170 □ Moving Large Blocks of Data, 174 □ Table and Register Moves, 175

---

**SECTION E  
ADVANCED INTERMEDIATE FUNCTIONS 181**

---

**15 Utilizing Digital Bits 183**

Introduction, 184 □ Bit Patterns in a Register, 184 □ The Bit Pick Contact, 185 □ Changing a Register Bit Status, 185 □ Application of BS, BC, and BF, 187 □ Shift Register Functions, 188 □ Summary of Shift Register Operation, 193 □ Shift Register Application—Light Pattern, 193 □ Shift Register Application—Code Output, 198

**16 The Sequencer Function 201**

Introduction, 202 □ The Mechanical Drum Controller, 202 □ A Three-by-Five Sequence Example, 203 □ The PLC SEQUENCER Function, 205 □ Format with Times Included, 211 □ Chaining Sequencers, 213



**17 Matrix Functions 217**

Introduction, 218 □ Where Matrix Functions are Effectively Used, 218 □  
The AND Matrix Function, 218 □ The OR Matrix Function, 223 □ The  
EXCLUSIVE OR Function, 223 □ The COMPLEMENT Function, 226 □  
The COMPARE Matrix, 228 □ Combination Matrix Operations, 228

---

**SECTION F  
ADVANCED FUNCTIONS 231**

---

**18 Controlling a Robot With a PLC 233**

Introduction, 234 □ A Basic Two-Axis Robot with Gripper, 234 □ PLC  
Sequence Control of a Basic Pick-and-Place Robot, 236 □ A More  
Complicated Robot, 236 □ Controlling an Industrial Pick-and-Place Robot,  
238 □ Creating a PLC Robot Control System, 241 □ A Drum/Sequencer  
Program for the Robot, 242

**19 Analog PLC Operation 247**

Introduction, 248 □ Types of PLC Analog Modules and Systems, 248 □  
Analog Signal Processing, 250 □ BCD or Multibit Data Processing, 254 □  
Chapter Examples, 255

**20 Networking PLCs 263**

Introduction, 264 □ Levels of Industrial Control, 264 □  
Computer-Integrated Manufacturing, 266 □ Network Communications, 269  
□ PLCs Role in Work Cell Networks, 271 □ Industrial Work Cells with  
PLC Networks, 274

**21 PID Control 279**

Introduction, 280 □ PID Principles, 280 □ Typical Process Control  
Curves, 281 □ Typical PLC PID Functions, 283

---

**SECTION G  
RELATED TOPICS 291**

---

**22 Number Conversions 293**

Introduction, 294 □ The Binary System, 294 □ Binary Coded Decimal  
Numbering System, 297 □ The Octal and Hex Codes, 300 □ Three Other  
Code Systems, 303