

PRACTICAL ELECTRICAL WIRING

16TH
EDITION

RESIDENTIAL, FARM, AND INDUSTRIAL
Based on the 1993 National Electrical Code®



HERBERT P. RICHTER
W. CREIGHTON SCHWAN

Practical Electrical Wiring

RESIDENTIAL, FARM, AND INDUSTRIAL

SIXTEENTH EDITION

*Based on the 1993 National Electrical Code**

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Preface to the Sixteenth Edition

For over fifty years *Practical Electrical Wiring* has been serving the needs of both students and practitioners of the art of electrical wiring. The first 10 editions were the work of H. P. Richter, whose ability to translate a complex subject into clear, simple, everyday language was outstanding. I have tried to follow the example he set.

New editions are issued as soon as possible after the appearance of the latest National Electrical Code®, which is revised on a three-year schedule. This sixteenth edition incorporates the applicable requirements found in the 1993 National Electrical Code®.

Electrical construction is a dynamic activity, with new products and new methods appearing continually, and I have tried to reflect herein those falling within the scope of this volume.

Suggestions for improvement of the book from readers will be most welcome.

W. CREIGHTON SCHWAN

Preface to the Ninth Edition

In preparing this book it has been the author's aim to make it simple enough for beginners, yet complete enough so that it will be of value also to those already engaged in electrical work. It is intended to be, not a manual that merely recites the methods used in wiring buildings for the use of electricity, but rather a book that explains the subject in such fashion that readers will learn both the *way* things are done and *why* they are done in that particular way. Only in this manner can students master the subject so that they can solve their own problems as they arise in actual practice, for no book can possibly cover all the different problems that are likely to arise.

Since this book is not intended to include the subject of electrical engineering, only so many basic engineering data as are essential have been included, and these so far as possible have been boiled down to ABC proportions.

All methods shown are in strict accordance with the National Electrical Code[®], but no attempt has been made to include a detailed explanation of *all* subjects covered by the Code. The Code is written to include any and all cases that might arise in wiring every type of structure from

the smallest cottage to the largest skyscraper; it covers ordinary wiring as well as those problems that come up only very rarely. The scope of this book has been limited to the wiring of structures of limited size and at ordinary voltages, at 600 volts or less. Skyscrapers and steel mills and projects of similar size involve problems that the student will not meet until long after he has mastered the contents of this book.

The book consists of three parts:

Part 1 presents the fundamentals of electrical work; terminology; basic principles; the theory behind general practices. Part 2 deals with the actual wiring of residential buildings and farms. Part 3 covers the actual wiring of nonresidential buildings, such as stores, factories, schools, and similar structures.

The science or principles of electricity do not change; the art or method of application does change. That portion of this book having to do with *principles* has in this ninth edition been revised and amplified to present such principles more clearly. That portion concerned with *methods* has been revised or rewritten as required by Code changes, to describe new materials and methods, and to outline the methods more clearly.

H. P. RICHTER

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PART 1

Theory and Basic Principles

Part 1 of this book is the introduction to practical electrical work, the ABC of the science and the art of electrical wiring. In order to master the art, naturally you must clearly understand the science or the principles involved. The terms used in the measurement of electricity, as well as the names of the devices used in wiring, must be at your finger tips.

For that reason a considerable portion of the material presented in Part 1 of this book emphasizes the "why" more than the "how." If you understand the "why," the "how" becomes obvious. Master both, and Parts 2 and 3 of this book will be relatively simple.

Codes, Inspections, and Product Approvals

The purpose of this book is to explain the types of electrical wiring, wiring materials, and equipment that are safe to use; how to install them in a safe manner; and why they are installed in certain ways so that electricity may be safely used as needed inside and outside of buildings.

Electricity Is Powerful. Under control, electricity safely performs an endless variety of work. But uncontrolled, it can be destructive. Electricity can be controlled if the right kinds of wiring and equipment are installed the right way. It can be dangerous if the wrong kinds of wiring or equipment are used, or even if the right kinds are improperly installed. And properly installed wiring and equipment can become dangerous if they are not properly maintained.

At best, improper electrical installations can be uneconomical and inconvenient. Moreover, they can result in higher insurance rates. But worst of all, unsafe installations can burn, maim, and kill.

The purpose of this book, then, is to explain how to properly install electrical wiring and equipment so that the completed installations will be safe, economical, and convenient—in short, so that instead of destroying, electricity will serve our needs.

National Electrical Code. The National Electrical Code (NEC)^{®*} is a set of rules and regulations that sets forth the proper methods for installing electrical materials so that the finished job will be *safe*. It is published by the National Fire Protection Association (NFPA), Batterymarch Park, Quincy, MA 02269. Hereafter, the National Electrical Code will be referred to in this book either as the Code or as the NEC. This book will contain excerpts, tables, etc., from the Code, all of which are reproduced by permission of the NFPA, the copyright holder. Any further reproduction of such excerpted material is not authorized without the express permission of the National Fire Protection Association.

NEC Committee. The National Electrical Code Committee of NFPA formulates the NEC. The NEC Committee has members representing all concerned parts of the electrical industry. The NEC Committee consists of a Correlating Committee and 20 technical committees, which are called Code-Making Panels. Each panel consists of nationally recognized experts in one or more fields. These experts revise and update the NEC at three-year intervals, in keeping with the state of the art, at which time new materials and methods are covered and any obsolete rules are deleted. Hence, some *section numbers* of the Code are changed from time to time even when the text itself remains unchanged.

After general agreement has been reached by the members of the various Code-Making Panels in regard to proposed additions, deletions, or revisions, the Correlating Committee determines that there are no conflicts among the requirements adopted by the several panels. After that has been done, the proposed new edition of the Code is voted on by the NFPA membership. If adopted, the new edition is submitted to the American National Standards Institute (ANSI). After adoption by ANSI, the new NEC becomes an American National Standard. Hence, the NEC is “NFPA 70-1993” and also “ANSI/NFPA 70.”

Clearly, then, the NEC is an authoritative code, and compliance with it will result in a safe installation if the installation is also maintained so as to *remain* in compliance. The word “authoritative” as used here means “an accepted source of expert information” rather than “the power to enforce,” since the Code does not become law unless legally adopted as a law or code in a particular locality.

Local Codes. Almost every locality has an electrical code or ordinance. Some of these “local” codes are state codes. Others are municipal, town,

*National Electrical Code[®] and NEC[®] are Registered Trademarks of the National Fire Protection Association, Inc., Quincy, MA.

or county codes. Local codes are based primarily on the National Electrical Code. Electrical installations in any locality must meet the requirements of the electrical code in that locality.

Some localities have local codes that are more restrictive than the National Electrical Code. For instance, some wiring methods that are permitted by the National Electrical Code either are not permitted at all by some local codes or else have additional restrictions imposed by some local codes. Other localities adopt the National Electrical Code without any changes.

Enforcement of the NEC. When the NEC is legally adopted by a city, town, state, or other governmental body as an official code of that governmental body, it becomes law; and compliance with the Code in that locality then becomes mandatory on the date it is officially adopted.

Author's Interpretation of the Code. The Code is concerned with safety only, as is proper for a safety code and as is made clear by the following statements excerpted from Sec. 90-1 of the Code:

This Code contains provisions considered necessary for safety. Compliance therewith and proper maintenance will result in an installation essentially free from hazard, but not necessarily efficient, convenient, or adequate for good service or future expansion of electrical use.

This Code is not intended as a design specification nor an instruction manual for untrained persons.*

The safety measures advocated in this book are based on Code requirements as the author interprets the 1993 Code. But since the Code is not intended as a design or instruction manual, this book will also cover practical design and installation methods and the economic and convenience aspects of the art as well as safety.

Anyone using this book must recognize that the author does not and cannot accept any liability from its use. However, much thought and care have gone into the development of the material covered in an effort to make the book useful to all who wish to use it.

It is essential for every person who installs electrical wiring and equipment to have and use a copy of the Code. In addition to other objectives of this book, one of the objectives is to make it easier for you to under-

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stand and use the Code. So get a copy of the 1993 Code, which is the current edition.¹

Format of the Code. The Code consists of an introduction and nine chapters. Each chapter contains several articles, except Chap. 9, which contains general tables and examples. Some articles are divided into parts, such as Parts A, B, etc. All articles are divided into sections. Many sections have subsections, and some have sub-subsections. Some sections or their subdivisions have numbered paragraphs. Some sections, subsections, etc., are followed by fine-print notes. All mandatory rules of the Code are in full-size print. The fine-print notes contain explanatory or informational material and are not mandatory rules.

In the Code, vertical lines in the margin of various pages show where changes, such as an added or a revised rule or an editorial change, have been made from the preceding edition; they show at a glance which material has been changed or is new. A black dot appears in the margin where material has been deleted, but be careful, for it may have been relocated to another place in the Code and not really deleted at all.

History of the Code. The first electrical code was the “Standard for Electric Light Wires, Lamps, Etc.” that was adopted by the New York Board of Fire Underwriters on Oct. 19, 1881. It contained seven rules, plus instructions for applying for permission to use electric lights. That was the ancestor of the NEC.

In May 1882, the National Board of Fire Underwriters adopted the rules drawn up by the New York Board of Fire Underwriters. Later, similar rules were adopted by various other groups. Finally, a committee consisting of representatives from the fire-insurance groups, the electric utility company association, and a number of other national organizations produced the first National Electrical Code in 1897. That was the first electrical code that represented *a nationwide consensus of the entire electrical industry without any single group having a dominant position.*

What Is the NFPA? The National Fire Protection Association is a non-profit voluntary membership organization. It has members not only in the United States but also in Canada and some 80 other foreign countries. No single group has a dominant role. Its membership is representative not only of the fire services, but also of architects, engineers, and other professions; of industry and commerce; of government agencies at local, state, regional, and national levels, including the military branches; of

¹ The 1993 Code can be obtained by sending \$36.65 per copy to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. Ask for “NFPA 70-1993.”

hospital and school administrators; and of any others that have vocational or even avocational interests in achieving a fire-safe environment, which has been the primary objective of the NFPA since its inception November 6, 1896. (As used here, the term “fire-safe” is used in its broadest sense and includes *all* facets of fire safety, including—but not limited to—electrical safety.) NFPA has been the sponsor of the National Electrical Code since the 1911 edition.

The many codes, standards, recommendations, and manuals that have been developed by NFPA technical committees, which are composed of nationally recognized experts in their respective fields, have been widely adopted by national and local governments and by private industry. One of these, the NEC, is the most widely adopted and used in the world.

Interpretations. Unfortunately many parts of the Code are interpreted differently by different people; the words of the Code mean different things to different people. The interpretations in this book are the opinions of the author, based on his experience and the opinions of others. There is no “official interpretation”² of the Code, and the Code in Sec. 90-4 makes it entirely clear that the local electrical inspector has the final word in any situation.

Permits. In many places it is necessary to get a permit from city, county, or state authorities before a wiring job can be started. The fees charged for permits generally are used to pay the expenses of electrical inspectors, whose work leads to safe, properly installed jobs. Power suppliers usually will not furnish power until an inspection certificate has been turned in.

Licenses. In some localities, electrical installations can be legally made only by licensed electricians or by persons who are supervised by a licensed electrician. Many localities in which licensing is required make an exception to the licensing law, allowing you to install wiring in your own home or farm. Other localities do not have such an exception. Ask the inspector in your locality about local rules, and *get a copy of the local code*.

Testing Laboratories. Although approval of all installations is the responsibility of the authority having jurisdiction (the inspector or the inspector’s supervisor), that person may (and normally does) base approval of wiring materials and equipment on prior listing of the materials and

² There are indeed “Formal Interpretations” of specific parts of the Code, but not of the Code as a whole. The method for requesting a Formal Interpretation of a specific provision is given in the “NFPA Regulations Governing Committee Projects.” Very few such interpretations are handed down.

equipment by a qualified testing laboratory, as provided in Sec. 90-6 of the Code, since the inspector has no means of making suitable tests of most types of material and equipment. Such laboratory "listing" (after testing) of products indicates the suitability of the products for their intended purpose. Then after the wiring and materials have been installed, it is the inspector who must determine whether acceptable materials have been used and properly installed. The inspector then approves the completed installation or turns it down until any deficiencies have been corrected.

There are several qualified testing laboratories, such as the Canadian Standards Association (CSA) and the Underwriters Laboratories of Canada, which operate in Canada; and the Factory Mutual Research Corporation (FM), ETL Testing Laboratories, Inc. (ETL), and United States Testing Co., Inc., which test a limited range of equipment. But the testing laboratory that is most widely used in the United States is Underwriters Laboratories Inc. (UL). Hence, for the sake of simplicity and brevity, the term "UL" will be used in this book instead of the term "qualified testing laboratory." Similarly, the term "inspector" will be used instead of the term "authority having jurisdiction."

But to amplify and clarify this discussion, note again that the UL does not "approve" anything because approval would connote something beyond its service. UL investigates, studies, experiments, and tests products, materials, and systems, and if they are found to meet the UL safety requirements, UL will list them, and the items are then described as "Listed by UL" or "UL Listed." UL does not *approve* the item; it "lists" it. It is therefore wrong to say "approved by UL." The Code in Art. 100 defines "approved" as "acceptable to the authority having jurisdiction."* The inspector *approves* an item after UL has *listed* it and it has been used or installed in accordance with any instructions included in the listing. See Sec. 110-3(b) of the Code.

Requirement for UL Listed Equipment. Some local ordinances require that only UL Listed materials and equipment be used, if the material and equipment is of the type that is normally Listed by UL. [Some types of material and equipment, such as some fastening devices, lamps (light bulbs),³ etc., are not Listed by UL.] Whether the ordinance requires such

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³ A lamp consists of a bulb—the glass enclosure—and various other parts. Sometimes a lamp is called a bulb. See Chap. 14 for a discussion of an incandes-

Listing or not, the inspector usually will not approve an installation where unlisted material or equipment has been used, if it is the type that could be Listed. This applies to material and equipment in general, such as wire, cord, cable, boxes, fuses, circuit breakers, switches, receptacles, panelboards, etc.⁴

Unsafe Junk. Some manufacturers do not submit their products for Listing for a good reason—they could not pass the required examination and tests. These products are junk—shoddy and unsafe to use. Even if slightly lower in initial cost, such unlisted products are by no means inexpensive. They are “cheap” but not inexpensive, for they may cost as much as the building in which they are installed—plus the contents of the building. The ultimate cost might be one or more human lives. Figure 1-1 shows the results of UL tests of two plug fuses tested in accordance with standard testing procedures. The upper one failed; the lower one passed, as will be explained under the next heading.

UL Tests Are Meaningful. In order for a test to be meaningful, the product must be tested under the most severe conditions that would be encountered when the product is being used as intended. There must also be a safety-factor allowance. A fuse, as one example, must be able to operate (blow) and open the circuit (turn the circuit off as a switch does) within a predetermined time, such as when a wire is overloaded beyond its safe capacity. However, it must also blow if there is a short circuit, in which case the current might be a hundred or more times as great as is the case in just an overloaded wire. In other words it must be able to blow when the current is the *maximum* amount available, and it must do that without exploding or disintegrating, which could start a fire.

As an example, the familiar plug fuse used in homes (and in other occupancies) is made only in ratings up to (but not exceeding) 30 amp. But UL tests plug fuses on an alternating-current (ac) circuit that can deliver 10 000 amp at 0.85–0.95 power factor, which was the amount of alternating current UL used to test the two fuses shown in Fig. 1-1. Each fuse is entirely surrounded by surgical cotton. The cotton on the lower fuse did not ignite when the fuse operated (blew). The fuse shown at the top not only burned up the cotton but severely damaged the fuseholder as well as itself. Some fuses explode while undergoing this test, sending

cent lamp. The term “lamp” has been extended to include floor or table “lamps,” which are actually portable lighting fixtures.

⁴ In addition to electrical products, UL also tests materials related to Burglary Protection and Signaling, Casualty and Chemical Hazards, Fire Protection, Heating, Air Conditioning, Refrigeration, and Marine.