

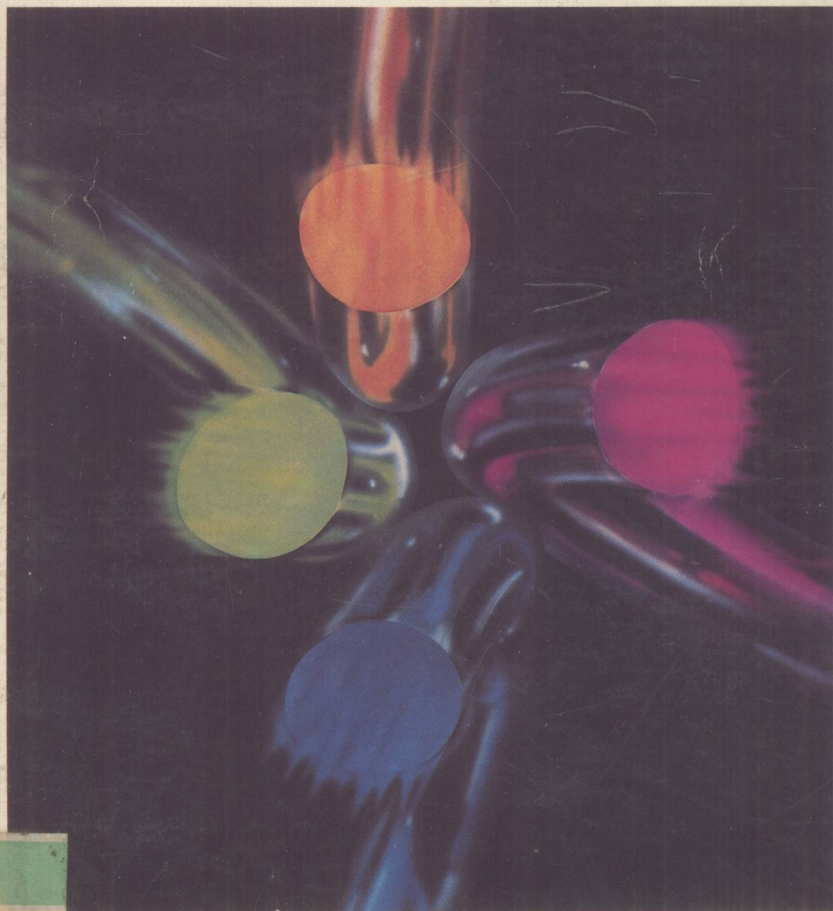


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# FIBER OPTICS

Communications, Experiments & Projects

Waldo T. Boyd



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# **Fiber Optics Communications, Experiments, and Projects**

by

**Waldo T. Boyd**



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## Preface

The transistor transformed the electronics industry in the space of some two decades. It did more than that; it was the germ that seeded a whole new way of life for the world. Bedouins in the desert, peons in the Mexican fields, and peasants in South America and Europe carry transistor radios to their sunup-to-sundown labors, in touch now with the events of the world.

When two catwhiskers were first applied to a block of crystal instead of just one as had been the case to that moment, the potential of the device that came into being was but dimly seen by a few dreamers in the world of vacuum-tube electronics. The first major computer, the ENIAC, was a gigantic apparatus with thousands of vacuum tubes giving off volumes of heat, with a few dedicated scientists and a flock of technicians at its heart. Vacuum tubes would never have spawned today's personal, home, and business microcomputers that are ENIAC's progeny.

Decades ago the dream was for a chicken in every pot, a car in every garage, and a radio in every parlor. Eventually the dream evolved into not only a tv in every living room, but also one in the kitchen, bedroom, and bath of virtually every home in the nation. People everywhere now have access to television via the satellites. But the television receiver is passive; the human animal may sit immobile in fascination a few months or years but becomes restless at last for an active part in the drama. And that need has been provided. The personal home computer provides an active interplay with the screen, and a prediction of a computer in every home is no idle dream. This has come about because of the transistor.

Another such transformation is taking place, barely noticed as yet in the hustle and bustle of everyday happenings in the world of electronics. This change is being thrust upon us by a discovery not of recent date, but of a half century or more ago. Light waves have been with us since the beginning of time, but what has come to pass in recent years is the ability to carry light for great distances through tiny "pipes." Just as we were reaching limits in the crowded electromagnetic frequency spectrum, we rediscovered the fact, almost obvious now, that light is but an extension of that spectrum, capable of carrying hundreds of television channels simultaneously in a slender filament of glass. Once more the vast potential of electronics has been tapped, this time with perhaps even greater significance than when the transistor burst upon the scene. We have a name for it: "fiber optics."

There are a few books available on the physics of light-carrying threads, but they treat the subject deeply and mathematically because they are written for the engineer and physicist. There is no need to add another textbook to the subject at this time. This book is written for the technician and intelligent electronics enthusiast who would like to keep abreast of significant developments in the field, and who would like some "hands on" experience. *Fiber Optics Communications, Experiments, and Projects* opens with a brief overview of the potential light has for the world of electronics, and an introduction into how it is channeled into hair-like threads.

As quickly as possible after covering the major aspects of light and the laws it obeys, we get into some experiments that demonstrate how easy it is to communicate via light beam. Each experiment builds on the one before to convey one more way to work intelligently with light. In the final experiments, you transmit and receive on your own fiber thread.

You begin with a simple light source, a tiny filament bulb known as a "grain of wheat" lamp. A simple photocell receives the light and transforms it into an electrical signal. You progress to the use of a special semiconductor device called a "light-emitting diode," or LED, to transmit light through a fiber, and a simple photodiode to detect that light at the far end of your system.

After the preliminary experiments, you will modulate a light beam with voice or music, and send the information-carrying beam through

a fiber to be intercepted by a phototransistor detector. The human voice is changed from waves in the atmosphere to electronic variations in a transistor, to light-wave variations, back again into electronic impulses in the receiver, and finally into sound waves in the air once again.

When the experiments are concluded, you will have become thoroughly fascinated with the potential of this new medium. Your rough experiments are all open and very interesting, but now you want to build a few "smooth" projects of lasting and practical value. In their turn, these projects are but one step toward the tomorrow that is certain to come for fiber optics. With the experiments and projects behind you, you will be ready to grasp the opportunities that are already arising in the industry for putting fiber optics to practical use.

Some of the "tomorrows" are already "today's." There is an office copier on the market today that owes its almost unbelievable contrast and sharpness in copying on ordinary paper to fiber optics. As for opportunities, home computers have two most annoying problems despite their popularity: they suffer from static electricity, and they give off radio-frequency interference. One of the most promising cures for these problems lies in fiber optics. It all begins here. Where it ends is up to you, because once you have grasped the principles of working with light, you will go on to solve such problems as these.

A number of suppliers of fibers, couplings, phototransistors, and LEDs have been most courteous in supplying materials from which to develop the experiments and projects herein. These are listed, with addresses, in Appendix D. In particular, I thank Corning for a generous supply of fiber, and AMP Incorporated for use of their engineering kit and for their kind permission to reproduce a number of illustrations from their excellent introductory handbook. Sylvania and General Electric supplied sample phototransistors, and Belden provided some multiple-strand cable. Radio Shack was most helpful in supplying hardware and electronics, and their part numbers are included for reference in obtaining components with which to duplicate the experiments; the "Archer" trademark designates the Radio Shack product.

The following people helped by providing technical materials and information as well as advice and assistance in writing this book: Peter Von Keyserling of AMP Inc., Hank Schroeder of Motorola, William

Hegberg of Opto Technology, Inc., Bill Nunely of TRW Optron, and James Pletcher of AMP Inc. Thanks are also due to Math Associates and Motorola for their assistance. The support of these people and companies is greatly appreciated.

I wish also to thank Richard Cunningham, editor of *Electro-Optical Systems Design* magazine, for his helpful encouragement in undertaking the task of writing this book. And I owe a debt of gratitude for invaluable advice and assistance to Dr. Jonathan Titus of The Blacksburg Group. His guidance has been one of those remarkable balances between praise and stern criticism which reveal the born teacher.

May this be but the first of your fascinating explorations into the most significant development since the transistor!

WALDO T. BOYD

*To My Grandson  
Duane Brown*

" . . . If comparison be made with the sum total of all former human achievements it will be found that the discoveries, scientific advancement and material civilization of this present century have equalled, yea far exceeded, the progress and outcome of one hundred former centuries."

— Abdul Baha' (1844— 1921)





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# **Section 1**

## **Fundamentals of Fiber Optics**

1. INTRODUCTION TO FIBER OPTICS
2. BASIC PRINCIPLES OF FIBER OPTICS
3. WHERE IT ALL STARTED
4. THE "NUTS AND BOLTS"
5. BASIC PRINCIPLES OF GLASS FIBERS
6. SIMPLE SYSTEMS



# 1 Introduction to Fiber Optics

Our universe is energy; everything we sense, measure, and experience is energy in one form or another. Sometimes energy is obviously in motion; sometimes it seems to be at rest, ready to perform some task at Nature's behest or man's command. The more we contemplate energy, the more awe-inspiring it becomes. All-pervasive, in and around us, governing our every action and reaction, determining our life or death, our coming and going, energy is the stuff of life and of the cosmos of which we are materially a part.

This is a book about energy. The particular kind of energy we shall consider is electromagnetic in nature, similar to the radio waves that bring our transistor radio to life with the music of the latest combo. However, the energy we shall explore is in very, very rapid vibration as compared to the broadcast radio wave. There is a name for energy that is alternating this rapidly: *light*.

Light was not often thought about in terms of energy before the invention of the laser. Now we know it as one of the most potent forms of energy we can imagine.

Few of us have taken time to think about the structure and function of our eyes. The eyes we take for granted during every waking moment are tiny, highly efficient "television receivers" that can differentiate among a multitude of frequencies and let us see color. Each specific color represents a certain frequency of electromagnetic energy, just as does one station tuned in on our radio. The retinas of our eyes contain marvelous "antennas" and detectors which respond to



these electromagnetic waves of energy in a manner that is, even in this enlightened scientific age, a profound mystery.

Our eyes are blind to the radio frequencies that our transistor radio is capable of sensing, and the radio is "deaf" to the frequencies our eyes can see. Our eyes are likewise blind to gamma rays that are emitted from radioactive substances or the physicist's cyclotron. Our marvelous light sensors gradually lose their ability to sense as the frequency of light extends down into the infrared region or up into the ultraviolet region.

Only a few years ago, the terms megahertz, gigahertz, and femtohertz were unknown, as were the facts involved in this very-high frequency portion of the spectrum. A few pioneering physicists wondered if we would one day be able to generate light waves in much the same manner that we do radio waves, up, up, and yet farther up into the extremely short waves measured in angstrom units ( $10^{-8}$  cm).

We reached that level of understanding and in due course were able to generate light directly, rather than by such means as a hot length of tungsten wire. Today our little hand-held calculators wink in response to our pressing the keys; the winking red lights originate in solid-state light generators called *light-emitting diodes* (LEDs). And in another way we can now cover the entire visible light spectrum with a device we call a *tunable laser*. ("Laser" is an acronym for Light Amplification by Stimulated Emission of Radiation.)

As we rolled forward the upper limits of generating electromagnetic waves, the amount of information we could code, or modulate, into a given place in the spectrum increased geometrically. Early in the days of radio communication, the cumbersome Alexanderson alternator served as the generator of electromagnetic waves at about 10,000 cycles per second. (In later years "cycles per second" came to be known as *hertz* (Hz), in recognition of the early experimenter who first identified radio waves, Heinrich Hertz.) The ten-ton alternator later was replaced by a water-cooled vacuum tube light enough to be hefted in one hand.

The amount of information that can be conveyed from one point to another with a carrier wave of only 10,000 Hz is limited to but a portion of the human voice range. When the vacuum tube was devel-