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Lightwave

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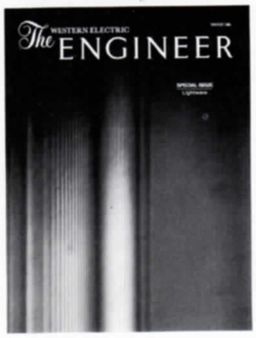
THE COVER



A fiber preform, the glass source material from which a lightguide fiber is drawn, was viewed from the side and illuminated from behind with polarized light. This photograph shows one half of the preform's cross-section. The axis of the core is at left, and, some of the glass protective cladding fills the right-hand half of the scene. The structure of a fiber drawn from such a preform would be virtually identical.

DEPARTMENTS

The photograph above appears in color on page 4, and it affords a new and insightful view into the nature of lightguide fiber manufacture. Like several other equally unique pictures in this issue, it was the result of the collaboration of Engineering Associate Richard Borutta of the Engineering Research Center. His solutions to problems were timely and helpful. The advice and suggestions of Laurence S. Watkins and Monsoor Saifi of the Research Center, and Robert B. Runk of Corporate Product Planning were especially valuable. The results of this assistance appear on the front cover of this issue, inside front cover, pages 4, 12, 48, 52, 53, 86, 96, and the inside and outside back covers. John Carnevale photographed the front cover, pages 12 and 96; Leo Derlak, inside front cover, pages 4, 48, 86, 96, and inside back cover; Leonard Stern, page 38; Chuck Lewis, page 80. Charles Brownmiller of Bell Laboratories, Reading, made the electron micrograph on page 24, Robert E. Woods of the Engineering Research Center made those on pages 50 and 51, and Richard Hunsberger of Reading Works made the micrograph on page 99. The photo on the back cover was made by Nancie Battaglia for the Lake Placid Olympics Organizing Committee.

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LIGHTWAVE SYSTEMS: AN OVERVIEW

Glass fibers will soon connect three Bell telephone offices in Atlanta, and links in Pittsburgh, San Francisco and New York City will go into service early next year. Lightwave technology's impact may turn out to be comparable to that of the semiconductor and integrated circuit. Certainly, it will open up opportunities to offer new telecommunications services in great variety.

by Melvin I. Cohen and Richard B. Snyder

ABSTRACT

Lightwave communications systems offer important advantages, including large bandwidth and low transmission loss. They also present special considerations, particularly for installation, maintenance, and repair. The first standard lightwave system installations will be in the short-haul metropolitan exchange portion of the telephone network. However, there are no technical barriers to other applications ranging from those on customers' premises to undersea links. Western Electric has made a major commitment to lightwave technology, in the expectation that its advantages will generate new products and services.

In April 1979, Western Electric announced plans to construct a full-scale manufacturing facility for lightguide cable and associated hardware. The facility, occupying 50,000 square feet at the Atlanta Works, represents an investment of over $10 million and is perhaps the most tangible evidence of the degree to which lightwave communication systems have advanced toward becoming practical, commercially viable products. It is also a demonstration of Western Electric's commitment to serve Bell operating company needs for advanced equipment and services by quickly moving lightwave technology from the laboratory to the field.

At the outset, a word about terminology is appropriate. The expression "lightwave communication" has been adopted to describe the use of light as a carrier of information.[1] The expression is consistent with terminology for other telecommunication media such as microwaves and millimeter waves. The earlier term "optical communication" often needs further definition because its colloquial usage also encompasses phenomena related to vision. "Lightwave" has the advantage of being accurate, descriptive, and more readily understandable. The glass fibers that carry lightwave communication are called "lightguides."

This special issue of *The Engineer* on lightwave communications contains articles on the theory, design, packaging, manufacturing, and installation of lightwave systems, in particular the FT3 metropolitan trunk system (for a description of how the lightwave systems work and of the FT3 system in particular, see *The FT3 Lightwave System*, page 8). FT3 (F stands for fiber and T3 means the third level for the digital transmission hierarchy), the Bell System's first standard lightwave communication system, will be placed in service by Southern Bell Telephone Company in the latter part of this year in Atlanta. This system will be the first of many standard systems that will be installed by Bell Operating Companies in major cities across the country over the next few years.

The purpose of this overview article is to describe the characteristics of lightwave systems, the importance of the technology to the Bell System and to Western Electric, and some of the significant elements of the Western Electric lightwave program.

CHARACTERISTICS OF LIGHTWAVE COMMUNICATION SYSTEMS

Lightwave systems possess several

Figure 1. Rings of glass are the core of a preform used to manufacture lightguide—glass fiber for communicating by lightwaves. The layered core and its uniform glass cladding (invisible in this photograph) are actually about one-half inch in diameter, and are later drawn into a fiber many kilometers long. Only 125 microns in diameter, the fiber replicates the layered structure of the preform, which ensures that lightwaves can travel long distances through the fiber without regeneration.

[1] S. J. Buchsbaum, *Physics Today*, special issue on lightwave communications, May 1976, p. 20.

unique characteristics, and consequently, offer unique opportunities; however, as is often the case, their use may present special considerations not encountered with conventional copper-based systems.

The unique characteristics of these systems are a result of two factors: the development of low-loss, low-dispersion glass fibers (see "Lightguide Theory and Its Implications in Manufacturing," page 12), and the development of semiconductor optical sources such as lasers and high-radiance light-emitting diodes (LEDs) (see "Lightwave Sources and Detectors," page 24). The most important characteristics are summarized in Table I.

From a communications standpoint the characteristics in the table all have positive consequences. As noted, however, lightwave systems have important differences with respect to copper systems, most of which are encountered in the outside-plant portion. (See "Installation of Lightguide Cable," page 102, and "Implementing Lightwave Systems," page 110.) For example, at the moment, splicing of glass fibers is quite different from splicing copper wires. Craft training is usually more complex, and the tools and techniques are not the same. However, because there are far fewer splices to make with lightguide cables than with copper, the total splice time may actually be less. In fact, the lightguide cable design chosen by the Bell System uses factory-attached mass splice connectors (see "Interconnection of Lightguide Fibers," page 86), an approach which substantially reduces craft effort and relegates single-fiber splicing to repair or other unusual situations.

Finally, because lightguide cables are presently more expensive than copper cables, and because optical-to-electrical interfacing is required, today's lightwave communication systems will find application primarily in situations where the "consequences" listed in Table I provide an economic value to the user that is greater than that of conventional approaches.

Lightwave technology is in its infancy, whereas competing, conventional technologies are either at or approaching maturity. Therefore, the *cost* of lightwave systems (both first cost and life-cycle cost) will come down, and that of copper-based systems will rise (see Figure 2). Furthermore, as designs continue to exploit the attributes of lightwave systems, their *value* will go up. Several effects are at work here: lightwave system manufacturing will become more efficient as more experience is acquired and as production volume climbs; meanwhile, the material costs of copper systems can be expected to rise steadily. At the same time, lightwave systems will be able to offer new services. All of this is by way of in-

BELL SYSTEM MILESTONES IN LIGHTWAVE COMMUNICATIONS

A chronology of notable achievements.

1880: ALEXANDER GRAHAM BELL'S "PHOTOPHONE." A mechanism varied the intensity of a beam of sunlight in response to speech vibrations. A receiver transformed the light variations into electricity (with a selenium detector), then into sound. The problem: the light weakened quickly as it traveled through the air.

1958: Invention of the laser by Schawlow and Townes.

1965: LOW-NOISE AVALANCHE PHOTO-DETECTOR. A solid-state device that converts light into a strong, clear electrical signal.

1970: DOUBLE HETEROSTRUCTURE SEMICONDUCTOR LASER. A small, manufacturable source of light that operates continuously at room temperature.

1972: MODIFIED CHEMICAL VAPOR DEPOSITION PROCESS (MCVD). Produces glass-fiber preforms of graded, precisely controlled composition and high purity.

1973: LABORATORY OPERATION OF 50 MEGABIT/SECOND LIGHTWAVE LINK. Demonstrated feasibility of high-capacity lightwave transmission.

1973: FIRST LOW-LOSS FIBER MADE BY MCVD PROCESS. Showed manufacturability of high-quality lightguide.

1975: SINGLE-FIBER MOLDED CONNECTOR. An inexpensive device for linking fibers with light sources and detectors.

1976: ATLANTA EXPERIMENT. A working lightwave transmission system was installed on the grounds of Western Electric's Atlanta Works.

1977: FIRST COMMERCIAL TRAFFIC carried over a lightwave system in Illinois Bell in trial in Chicago.

1979: FIRST SERVICE OVER PERMANENT ROUTE, in Connecticut, Southern New England Telephone.

1980: FIRST STANDARD LIGHTWAVE SYSTEM, the FT3, scheduled to go into service with Southern Bell in Atlanta.

troduction to the next section, which examines the impact of the new technology on the Bell System in general and on Western Electric.

LIGHTWAVE TECHNOLOGY AND THE BELL SYSTEM

Not since microwave radio has there been as significant a technology developed in telecommunications as lightwave technology.

At the present time, the Bell System has approximately $80 billion invested in the outside-plant portion of the network. For the past few years, the Bell System has been spending 25 percent of its construction budget in the outside plant. In 1979, that percentage amounted to almost $4 billion. Also, maintenance expense in this area has been a significant portion of the total dollars spent on maintenance, and, recently, has been growing at a rate of 17 percent annually.

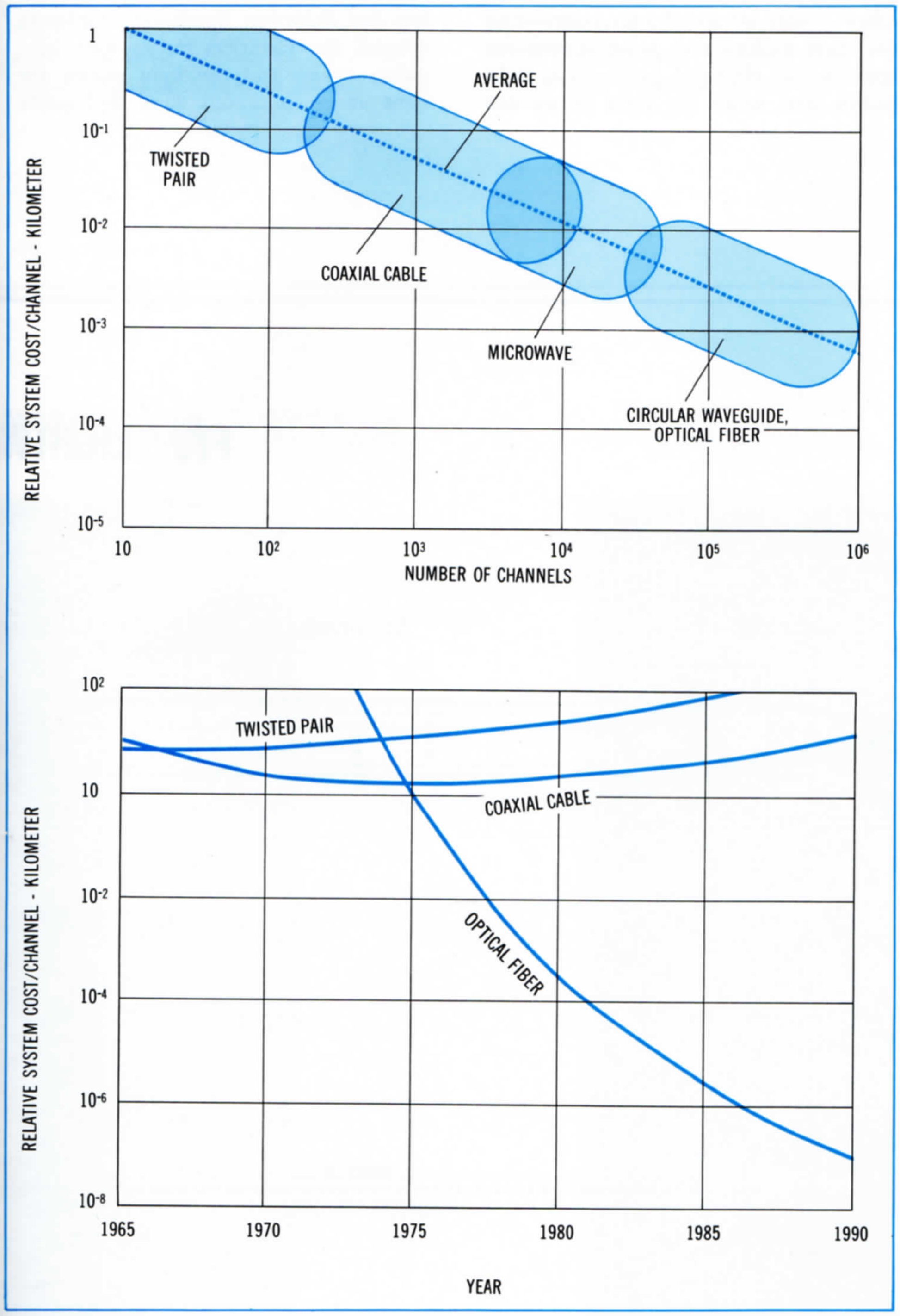

Figure 2. As channel capacity of a telecommunications system increases, the cost per voice channel decreases. In addition, as development of lightwave systems continues and manufacturing experience is accumulated, the cost of such systems will decrease. These trends are shown above in plots based on forecasts from a recent market study by Gnostic Concepts Inc.

The FT3 lightwave system being introduced this year will allow a 100-fold reduction in the number of regenerators normally required by today's T1 digital transmission system using copper cables. This reduction results from both increased repeater spacing and higher message capacity. Moreover, most of this electronics is outside the central office. It is clear, therefore, that lightwave systems will help operating companies avoid considerable maintenance expense in the outside plant. In addition, operating companies frequently will avoid large capital construction expenses for projects to place new cable and/or ducts by using lightwave systems, because of their large message-carrying capability and small cable size.

Optical fibers are inherently versatile as a transmission medium. They come as close to being a "virtual pipe" as anything that is around right now; that is, all forms of information, be it voice, video, or data, can be carried on a fiber. And, because of lightguide's large bandwidth, any or all of these information forms can be transmitted simultaneously with specific portions of the total "pipe" assigned and reassigned to specific uses as needed. Consequently, lightwave systems have the potential to provide the Bell System with new service offerings and thus with increased revenues.

Finally, lightwave systems are ideally suited to the high bandwidth requirement of digital transmission, and hence are well-matched to the evolving Bell System network.

LIGHTWAVE TECHNOLOGY AND WESTERN ELECTRIC

While the specific timing of events is uncertain, it can be stated safely that lightguide fibers will find their way

(Continued on page 10)