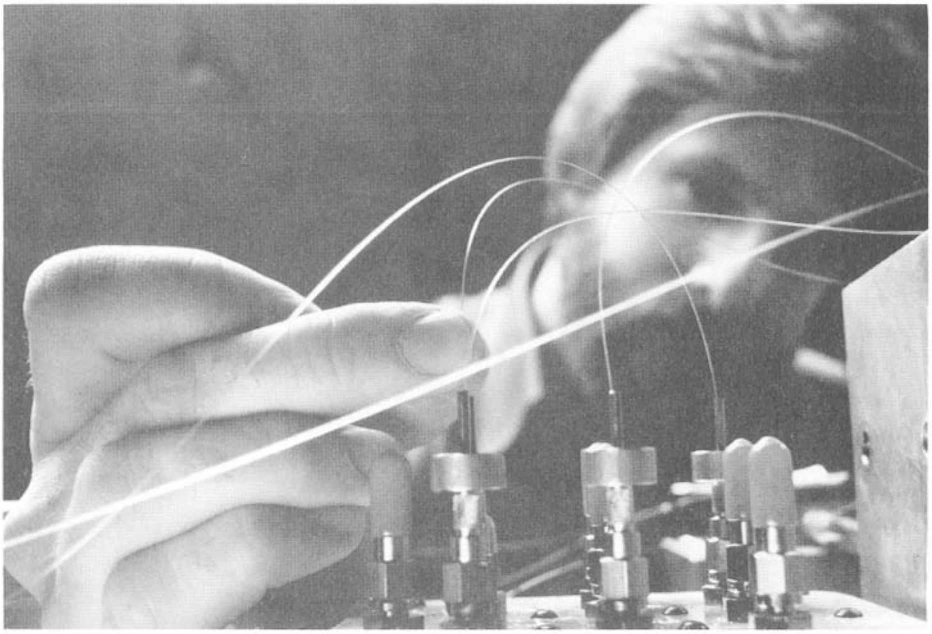
Fiber optics: expectations achieved but some optical illusions remain

Second installment in a series by Howard Rausch

Like the laser in *its* early days, lightwave transmission—a.k.a. fiber-optic communication—is basking in a limelight that's a blend of realistic expectations and optical illusion.

It has fulfilled most reasonable growth forecasts. This year it's a $600 million activity, twice its 1981 size. Growth of that magnitude gives rise to *the first illusion*: that lightwave transmission has finally fulfilled its research dream and become a booming business. Yet all sales of fibers and cables in the United States this year, together with sales of related components, will fall considerably short of the dollar volume of electrical relays. Fiber shipments are expected to total a quarter of a million kilometers this year. That's up nearly 50 percent from 1982, a healthy increase by any standard, enough to cast a shadow on the 2 million kilometers of metal conductor installed annually in the United States.

This increasing share of new installations gives rise to *the second illusion*: that lightwave transmission, long considered the wave of the future, has suddenly become the irresistable wave of the present in communications. It's easy to forget, in this euphoria, that fiber optics is competing successfully against copper only in long-distance communications—a mere 6 percent of the communications field. And both media take a back seat to wireless transmission. Tall towers scattered throughout most of the American heartland bear silent testimony to the dominant role played by microwave in transcontinental calls. American Telephone & Telegraph Co. calculates that two-thirds of all long-haul traffic uses this technology; coaxial cable accounts for another one-quarter. Most of the rest, at least in the United States, is relayed by satellite.


FIBERS READIED: Measuring optical fiber at Valtec, a Philips N.V. affiliate in West Boylston, Mass.

Lightwave development: the first quarter century

1958 – Invention of laser; beginning of applied research in lightwave transmission
1961 – Bell Laboratories begins system research
1962 – First semiconductor lasers at IBM and Lincoln Laboratory
1966 – Prediction of practicality of fiber communications
1969 – Graded-index fiber demonstrated
1970 – First low-loss (20 dB/Km) fiber at Corning Glass
1974 – MCVD process for making fibers
1976 – Atlanta system experiment
1977 – Chicago system trial
1980 – First standard FT3 service. This Bell System standard transmits 45 megabits per second.
1983 – FT3C long-haul service. This standard transmits 90 Mbit/sec.

Those fiber-optics orders are hotly sought by 500 suppliers of fiber, cable, components and equipment for their manufacture, installation and service. The industry is clearly attracting new companies, giving rise to *illusion No. 3*: that here's a place where money is to be made. Under such competitive conditions, however, large sectors of the business remain unprofitable. Many winners of contracts are no more profitable than the losers. A few companies—especially fiber suppliers—have earned more from selling shares of stock than from equipment or services.

The technology's superiority to wire-based communication is also a mixed blessing. Fiber does indeed carry more data a longer distance without repeaters. But *illusion No. 4*, technical omnipotence, disguises hardware problems. The possibility to cram a gigabit per second into a single fiber first requires lining up those bits. If a high-capacity fiber can carry 100,000 telephone lines, then 99,999 of every 100,000 bits would be for someone else's conversation. Time-division multiplexing at the required speeds and densities does not yet exist.

There's also danger in concentrating all those phone calls in a single link. If a rabbit should chew through the cable—as happened on British Telecom's Birmingham-to-Ipswich link—there's a sudden and longlasting absence of phone lines. More common is the interruption caused when a bulldozer plows through a link. So frequent are such interruptions that they're beginning to be provided for in transmission specifications. Deutsches Bundepost's newest specs, for example, allow for attenuation at as many as two splices in each kilometer of cable. Attenuation at the splices can exceed losses in an entire line during its 25-year expected lifetime. Multiple and redundant links of lower density and lower technology do have some practical advantages.

Like the laser, lightwave transmission has benefited from huge investments of brainpower since its inception in 1966. At that time Charles Kao, then at Standard Telecommunications Laboratories in England, proposed its development for telecommunications. Since then, the technology has attracted 30,000 man-years of research, including efforts in such components as semiconductor lasers and detectors. For comparison, design of copper-based systems is estimated to have required only 20,000 man-years in the past century. This year the United States military, for example, is expected to spend close to $90 million on research and development of lightwave transmissions.

During these years of intensive research and publicity, there have been many premature predictions of copper's demise at the hands of lightwave transmission. In 1975, for example, *Business Week* reported that optical fibers were expected to make many applications of copper obsolete before the decade was out. In the following two years, the article continued, "telephone operating companies will be replacing copper with fibers. The value of the (recovered) copper may more than cover the replacement cost."

COPPER STILL ALIVE

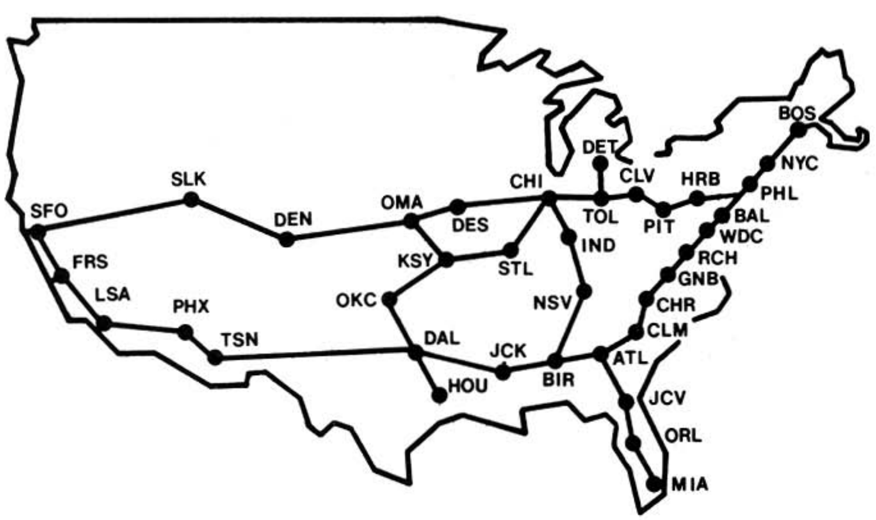
How much has copper demand been restrained by lightwave? Not nearly as seriously as *illusion No. 5* would indicate. Not even as severely as the reductions allowed by the use of electronic data compression techniques. Signal multiplexing, for example, allows many digitally encoded signals to pass along a conductor that could otherwise transmit only a few. As a result of multiplexing, the transmission of 672 voice channels at 45 megabits per second—a standard telecommunications data rate—over 3.5 miles now requires only slightly more than 1100 pounds of coaxial conductor, down from the 16 tons of twisted wire pairs, that were needed just a few years ago. The same signal, incidentally, could be transmitted through optical fiber that weighs less than one pound.

As we've seen, optical technology outperforms others for long-haul, high-data-rate links and seems certain to dominate new network installations. This trend is enhanced by the recent surge in popularity of single-mode fibers, despite formidable technical difficulties in coupling light into a fiber core only a few micrometers in diameter. Hence both the Bell System and MCI Telecommunications Corp. are investing heavily in lightwave transmission as the backbone of their future systems. AT&T's Long Lines Dept.—the operting arm which will remain after divestiture of local phone companies is completed—plans to install 1920 route-kilometers of single-mode fiber links, containing 43,000 km of fiber, by 1986. MCI has begun to install 6800 kilometers along railroad rights of way in the eastern United States.

MCI's orders, the largest in single-mode transmission, are reported to involve a billion dollars in capital equipment. There's a question whether all of this hardware exists, however, outside the Bell System, which has demonstrated its own. Elsewhere in the industry, transmitters and receivers for single-mode fibers are still being made only in developmental quantities, according to John N. Kessler, president of Kessler Marketing Intelligence in Newport, R.I. A year-end survey by *Lasers & Applications* magazine found only one company that claimed to offer commercial connectors intended specifically for single-mode fibers.

So clear is fiber's superiority to metal that Clifton Williamson, an assistant vice president of AT&T, states bluntly: "The copper trunk cable market will virtually disappear." Before jumping to *illusion No. 6*, however—that fiber has begun to take over copper's entire communications market—bear in mind that trunk cable constitutes only 6 percent of the communication system in the U.S. The rest is in the "subscriber loop," encompassing everything between the local exchange and your telephone. Of this massive quantity of wire and cable, fully 70 percent is in the last portion of the subscriber loop, the length between the intermediary signal distributor—the "serving-area interface"—and the customer's phone.

Can optical fibers take over here too? The Copper Development Association in New York expresses doubt "that any significant penetration of the subscriber loop will occur in the near term." The association's members have a lot at stake. Because copper wire pairs were the first means for transmitting telephone calls, there's a truly astronomical amount of copper installed in the ground or along telephone poles: 1.1 billion conductor-miles in the Bell System alone. That's the



POTENTIAL AT&T LIGHTWAVE TRANSMISSION IN 1995: The map above, prepared by the telephone company, envisions 10,000 route-miles and 300,000 total miles of fiber. Rapid expansion of fiber installation in U.S. is shown below.

YEAR	ROUTE MILES	FIBER MILES
1979	6	310
1980	20	3,700
1981	120	34,000
1982	1,300	94,000
TOTAL	1,446	132,010

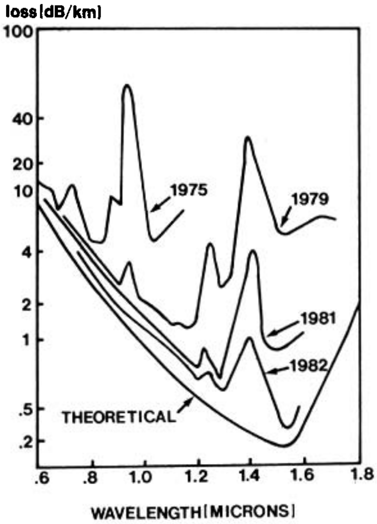
equivalent of twice the circumference of the earth's orbit around the sun.

If this copper, valued at $40 billion, should suddenly become obsolete, it could constitute the world's largest copper mine—and copper prices could collapse. As it is, copper is its own toughest competitor. One-third of the copper installed this year for the Bell System will consist of 909,000 kilometers of reclaimed metal.

Overcoming attenuation

Attenuation in fiber has complex composition. Its principal ingredient varies with the wavelength employed. Below 1200 nanometers, Rayleigh scattering dominates. At longer wavelengths, absorption features—notably those of the OH ion—dominate. Losses are lowest at 1500 nanometers. At present, long-haul lightwave systems are based at 1300 nanometers because of availability of good light sources.

At Bell Laboratories, systems operating at 1550 nm have transmitted one gigabit per second on a 70-kilometer link without repeaters. With losses below 0.01 decibel per kilometer, deemed attainable with metal-halide glasses, it would be possible to space repeaters as far apart as 1000 kilometers, according to Charles Kao of International Telephone & Telegraph's Advanced Technology Center.



CONQUEST OF ATTENUATION: **From around 10 decibels per kilometer just eight years ago, losses in optical fiber are now routinely held below 0.8 dB at a wavelength, or operating frequency, of 1.3 microns. Lowest curve represents the theoretical boundary for loss in silica fiber. Bell Laboratories predicts fiber losses of less than 0.001 dB/km for certain halide-based compounds.**

Three types of fiber

Optical fibers come in three main types: step index, graded index and single mode.

Step-index fiber is characterized by a sharp distinction between the refractive index of the core and the lower index of the cladding. This type of fiber has limited value for telecommunications because of different propagation paths within the fiber. These allow pulses launched into the fiber at different angles to arrive at their destination at varying times.

Graded-index fiber avoids this effect. It counteracts the inequality in path length by having a carefully controlled refractive-index profile, so the light that follows a geometrically longer optical path zigzagging through an outer area of lower index arrives at the receiver at the same time as does light which follows a path closer to the center. Graded-index fibers are available with bandwidth-length products of up to 600 megahertz-kilometers.

Single-mode fibers accommodate larger bandwidths. Here a single mode propagates and the material's inherent dispersion is counteracted by waveguide dispersion. This is the type of fiber used for long-haul links. The fiber composition usually provides zero dispersion at 1300 nanometers. Bandwidth-lengths substantially greater than 20 gigahertz-kilometers are common.

With all this copper already installed, lightwave transmission seems unlikely to mount strong competition in the subscriber loop based on price alone. It must allow more and better services at a small increment in cost. Several prototypes of such service systems already exist.

Complete lightwave systems, with optical transmission extending all the way to the individual subscriber, have been demonstrated in "fibered cities"—more accurately "fibered neighborhoods" in Biarritz, France, and Tokyo. In Biarritz, optical fibers are being installed to 5000 households. The services available will include cable television distribution, 12 channels of stereo sound, picturephones, ordinary telephone service and an interactive videotext system. The average link between a signal-switching station and the households it serves is only 800 meters long. For such length, it is feasible to use low-cost short-wavelength transmission, employing gallium-arsenide lasers and incoherent light-emitting diodes operating at 850 nanometers, with detection by silicon p-i-n or avalanche photodiodes. At 850 nm, attenuation is typically more than six decibels per kilometer, but the losses between the source and the detector are still low enough to allow adequate signal-to-noise ratio at the receiver.

COMPLEX COST ISSUES

Although the Biarritz system is not yet fully operational, its economics seem ominous. Cost is reported unofficially to total $40,000 per household. Tokyo's Hi Ovis project is said to incur similar costs. The French seem unconcerned that costs will remain so high, however. In May their government was reviewing plans to "fiber" more than one million additional households in Paris, Lyons and Biarritz by the end of the decade.

Another approach to network use of fiber is the "broadband network" being installed by Saskatchewan Telecommunications in western Canada. Here the terrain and population densities differ sharply from those in Biarritz and Tokyo, and the technology differs in important ways.

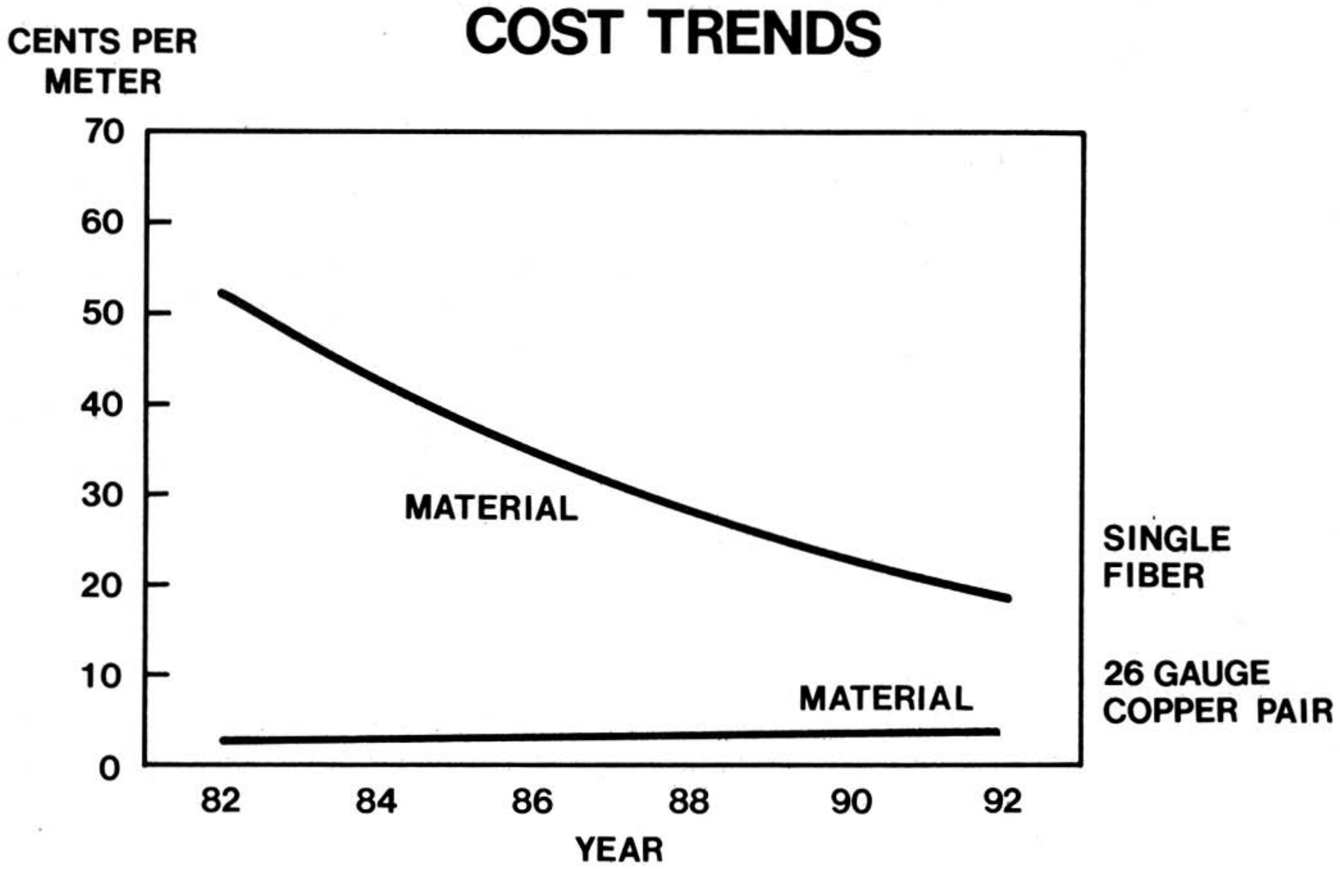
The 3200-kilometer lightwave network, until recently the world's longest, delivers both cable television and conventional telephone service to 190,000 households in the province's principal population centers: from Swift Current to Yorkton, for example, and from Regina to Moose Jaw. To serve the spacious province, Northern Telecom built a fiber-drawing plant that's at least the second-largest in North America and possibly the largest, employing about 700 people.

If lightwave transmission does make significant incursions in copper's subscriber loops, these could come first at corporate facilities, where high-data-rate optical links may prove valuable enough to justify the companies' performing their own demultiplexing. Another inviting application is cable television, combined with telephone transmission. Western Electric, the manufacturing arm of AT&T, already builds a lightwave system equivalent to its SLC-96, which carries 96 voice channels and is designed for the subscriber loops of existing phone systems.

After subscriber loops, the next most attractive field for lightwave transmission is the computer data network. Fiber-optic local-area networks have received considerable attention, but supplies have been almost entirely custom. It's still difficult to find off-the-shelf equipment.

This market has two major elements: point-to-point links and data networks. Point-to-point generally requires inexpensive plastic-fiber links that transmit a few kilobits per second over a few meters. Data networks provide transmission, typically at 100 megabits per second, between central processing computers and peripherals several kilometers away.

For longer distances, microwave's appeal is based largely on the installed base of costly equipment. But it offers performance advantages as well. Line-of-sight transmission can be much simpler than buried cables of any kind, especially in



NARROWING THE COST GAP: Cost of a single fiber should continue to decline toward that of 26-gauge copper pair. Curve assumes that price of fiber will continue to decrease by 10% per year while price of copper cable inflates at 6% per year. Savings in engineering and installation taken into account here, bring the differential down from sixfold to double in 10 years. At only twice the cost of copper, fiber begins to look more attractive because of its greater potential, says Clifton R. Williamson, an assistant vice president for network design at AT&T.

getting signals across a large body of water—or even the Grand Canyon.

Ironically, it's the newest technology, satellite transmission, that seems ripest for lightwave competition. Existing communication satellites are so underutilized that an advisory committee to the Federal Communications Commission is considering urging a 30 percent reduction in requirements for satellite-borne transponders, the receiver/transmitter systems. The principal reason given is the emergence of fiber optics, but the weaker-than-expected appeal of teleconferencing is certainly another factor. The committee also is establishing a study group to analyze the probable impact of fiber optics on the satellite industry.

FCC chairman Mark Fowler told an international satellite symposium in Los Angeles a few months ago that fiber optics was becoming the preferred medium for international television transmission. The reasons aren't all technical. When a satellite is used to transmit a program, it's difficult to confine reception to one country. Frequently, residents of a neighboring country can receive the broadcast as well. If the neighboring country would rather not receive that broadcast, it may jam it. It's a lot simpler to halt the flow through cable than to screen out a satellite signal.

When fiber-based systems are installed, only one advantage would remain with satellite systems: rapid deployment. After a company receives permission to bring signals into an area, it needs only to redirect a satellite aerial and build a ground-receiver. Then, when fibers are brought into town, the signals can be cut over to the lightwave system and the satellite can be redeployed.

Fiber-optic communication is clearly the wave of the future. But it's an illusion to expect either copper or microwave to become suddenly obsolete.

Acknowledgment: John P. Ryan provided valuable assistance in the preparation of this article.—**Howard Rausch**

Wavelength division multiplexing

By assigning a different wavelength to each optical data stream, it is possible to transmit several bit streams simultaneously. Each bit stream is generated by its own light source. With an appropriate set of filters, these streams are combined into one fiber. At the receiver, multilayer dielectric-coating filters separate the different wavelengths, which are then decoded by individual detector/amplifier combinations.

No systems now use this data multiplexing scheme in the field, but there is growing interest in wavelength division multiplexing as a way to avoid rapid obsolescence of new installations. Hence lightwave systems now being designed for use at 1300 nm and contemplating sources at 1300 nm are typically specified to allow single-mode operation at 1200 nm and to have acceptable dispersion at 1500 nm. A system specified this way could triple its data capacity after installation by using 1200 and 1550 nm as secondary wavelengths in wavelength division multiplexing.