couraging but by no means conclusive.

This Yin-Yang hypothesis, then, is still a hypothesis. It is interesting in that it unifies diverse results and permits investigators to make predictions that can be experimentally tested. It is becoming increasingly clear that cyclic AMP cannot, by itself, regulate all bidirectional systems. The Yin-Yang hypothesis can give direction to new research in cellular regulation.

—GINA BARI KOLATA

Additional Readings

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Optical Communications: Specialized Applications Appear First

Telephone traffic is increasing at a rate of 15 percent per year (measured in voice circuit miles). Data transmission and video transmission are increasing at 25 and 35 percent per year, respectively (measured in binary bits transmitted). These are the projections for continued growth in telecommunications traffic contained in a report recently released by the National Academy of Engineering. One of the current approaches to meeting this rapidly increasing demand in communications capacity is the development of systems in which light waves transmit information. Optical systems can accommodate large volumes of information, because of the much greater magnitude of optical frequencies compared to those of the information being transmitted. Although they are still largely in a research and development stage, a few optical communications systems for specialized applications are being tested.

Among the components of such a system are a light source to generate the optical carrier wave, a modulator to impress the signal to be transmitted onto the light wave, and a photodetector to receive the modulated light wave at the end of the transmission path. The light is transmitted either through a glass optical fiber or through the air. In addition, electronic devices are required to convert the information signal into a form suitable for driving the modulator and to recover the signal from the photodetector.

For example, an experimental telephone system is being operated aboard the Navy cruiser U.S.S. *Little Rock.* This system, put together by the Naval Electronics Laboratory Center, San Diego, California, consists of a gallium arsenide light-emitting diode (LED) source, a silicon detector made from a p-n junction with an intrinsic layer between the p- and n-type regions (PIN photodiode), and glass optical fiber transmission lines. Although the loss in light intensity as the light travels through the fiber (that is, the optical attenuation) is not particularly low, this is not a problem for the short distances that messages travel on board a ship. Modulation is achieved directly by controlling the current through the gallium arsenide LED. According to Donald Albares of the Naval Electronic Laboratory Center, the telephone system operates at 3 to 4 kilohertz (audio bandwidth), and therefore does not tax the performance limits of any of its components. Optical fiber telephone systems are of special interest to the Navy because of security considerations. Fibers do not radiate signals, and hence are safe channels of communication; fibers also are not subject to interference from neighboring signals and therefore are not subject to cross talk. An operational demonstration of a closed circuit television that can transmit visual information aboard a ship is planned for the near future.

Low Attenuation Glass Fibers

Terrestrial optical communications systems, like the Navy's shipboard telephone system, will most likely use glass optical fibers as the transmission medium. However, long-distance transmission through fibers does not become practical unless a very low optical attenuation level is reached. The first breakthrough in the development of optical fibers was reported by researchers at Corning Glass Works, Corning, New York, nearly 3 years ago, when fibers with optical attenuations of 20 decibels per kilometer (compared to previous attenuations of more than 100 db/km) were produced. Since then, Corning has made, on a laboratory scale, fibers with attenuations as low as 2 db/km (at some wavelengths), according to Robert D. Maurer, manager of applied physics research at Corning. Corning's fibers, made from two different glasses, have an inner core with a higher index of refraction and an outer cladding with a lower index of refraction. The difference between the indices of refraction of the core and of the cladding causes the light to be confined to the fiber. The small diameter fiber is made by drawing down in a furnace a rod within a tube; in this way core diameters as small as 3 micrometers have been obtained. Before optical systems that depend on fibers are practical, researchers must learn how to make long lengths of fibers, how to make fiber bundles and cables, and how to join fibers together. Corning has developed some prototype cables and coupling devices.

Bell Telephone Laboratories, Holmdel, New Jersey, is also pursuing research in fiber development and has recently produced fibers with attenuations almost as low as those of the best Corning fibers. The Bell fibers, unlike those of Corning, use the same glass in the core and cladding, but the core and cladding are separated by an air space (Fig. 1). Since the air has a lower index of refraction than the glass, light is still confined to the fiber. Bell is also studying other kinds of optical fibers, including one similar to the Corning design. A third kind of fiber, developed at the Nippon Electric Company in Japan, has an index of refraction that varies continuously from the center to the surface of the fiber. This graded index of refraction also results in the confinement of the light.

An optical communications system having fibers with lower attenuations than those in the Navy shipboard experiment is being developed by GTE Laboratories, Waltham, Massachusetts. They are currently studying fibers that have a graded index of refraction (obtained from Japan), although other types of fibers are under consideration. Coupling devices to join fibers are also being developed. In other respects, the GTE system resembles those in which optical fibers are currently used. An aluminum gallium arsenide LED (emitting at 0.82 μm) is the source. A silicon PIN avalanche photodiode is used as a detector. Appropriate electronics modulate the LED source and recover the signal from the detector. In addition, GTE is making progress with repeater stations (consisting of a silicon detector, amplifying electronics, and an LED source) that will amplify attenuated signals at intervals along the transmission path. According to Brian Dale of GTE Laboratories, field tests of this system have not been made as yet.

Because of the uncertainties of the propagation of light through clouds, fog, rain, or snow, optical communications systems relying on atmospheric propagation are not seriously considered by most researchers for long-distance terrestrial communication. Short-distance communication through the atmosphere, however, may be quite attractive for urban areas. A model system for atmospheric transmission of digital (as opposed to analog) information is being tested, for example, under the direction of Bernard King of the Transmission Techniques Research Laboratory at Bell Telephone Laboratories. So far, experiments at three locations in New York City and one in Holmdel in which gallium arsenide LED sources (emitting at 0.9 μm) and photomultiplier tube detectors are used have indicated that reliable communication (1 hour lost per year) can be obtained over distances of 300 meters in the city. The lowest signal losses were obtained in the city near the ground (fourth floor), and higher losses occurred at greater heights in the city (20th floor and above) and at Holmdel. To begin very shortly are further tests on a similar system (employing silicon PIN photodiode detectors) that will simultaneously transmit 1000 channels each carrying up to 2400 binary bits of information per second. The overall data rate will be 12 megabits per second. Commercially made atmospheric data transmission systems that operate at lower data rates are now available from several manufacturers.

Optical communications systems that can transmit more than 100 megabits/sec (a high data rate) over long distances probably will be based on laser light sources, rather than on the LED. Optical systems for transmission of data from one satellite to another are being developed by the Air Force Avionics Laboratory's 405B Program Office, Wright-Patterson AFB, Ohio; these are

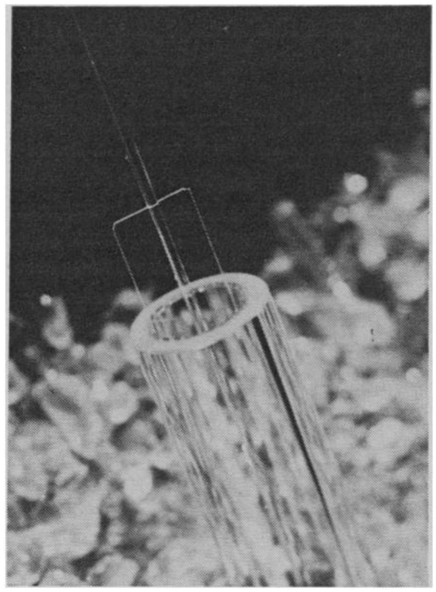

Fig. 1. The three components of a single-material optical fiber prior to the drawing process that will reduce the assembly to the diameter of a human hair. All three components—central rod, supporting plate, and tubing—are made of the same kind of glass. [Source: Bell Telephone Laboratories]

operating in the laboratory at data rates of the order of 1 gigabit per second (10^9 bits per second). Two systems, one designed by the Lockheed Missiles and Space Company, Palo Alto, California, and one by the McDonnell Douglas Astronautics Company East, St. Louis, Missouri, will be evaluated. One of these two will be selected for further development and subsequent testing. A space flight is planned for late in the 1970's, according to Major Paul Freedman, manager of the 405B program.

Each of the two satellite systems is based on a neodymium-doped yttrium aluminum garnet (YAG) solid state laser; but, whereas Lockheed uses a continuous wave laser operating in a single longitudinal mode, McDonnell Douglas uses a mode locked, pulsed laser. They both employ barium sodium niobate crystals to convert the infrared laser light (1.06 μm) to green light (0.53 μm), an operation known as second harmonic generation or frequency doubling. Modulation is achieved with the use of lithium tantalate electrooptic crystals. Although the details of the modulation differ, the electronically processed data signal drives the electrooptic modulator (instead of driving the light source itself as in the LED systems). Specially developed photomultiplier tube detectors of the dynamic crossed field type are used by both Lockheed and McDonnell Douglas.

At NASA's Goddard Space Flight Center, Greenbelt, Maryland, work is progressing on a gas laser satellite-to-satellite communication system, as well as on a neodymium-doped YAG system. According to Henry Plotkin, associate chief of the Advanced Data Systems Division, the first system is based on a carbon dioxide gas laser (emitting at 10.6 μm), which is thought by many scientists to be more reliable and longer-lived than the solid state YAG laser because of problems associated with the low efficiency with which neodymium-doped YAG absorbs the light which initiates the lasing action. The carbon dioxide system requires a heterodyne detection system. Heterodyne detection is extremely sensitive, but a constantly changing Doppler frequency shift caused by the relative motion of the receiving and transmitting satellites must be compensated for. The infrared heterodyne detector must also be cooled to about −120°C in order to overcome thermal noise. One possible disadvantage of the YAG-based system is the more complex tracking equipment needed to keep the transmitting and receiving stations aligned because the YAG laser beam is spatially narrower.

Just when optical communications systems will be needed is still a matter of much debate. To take full advantage of the information carrying capacity of optical systems, rates for voice, video, and data transmission equivalent to 100 gigabits per second or more will ultimately be required (more than 100 times the capacity of the Air Force experimental satellite system). This kind of performance depends on further improvements of lasers, miniaturized thin film optical circuitry (*Science*, 14 September, p. 1032), and optical fibers. In the meantime, features of currently developed optical fibers, such as their small size, light weight, freedom from electrical interference, and low cost, may be the decisive factors in the implementation of commercial optical communications systems.

—Arthur L. Robinson

Additional Readings

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