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ABSTRACT

Fiber optic communications (communications over very pure glass transmission channels of diameter comparable to a human hair) is an emerging technology which promises most improvements in communications capacity at reasonable cost. The fiber transmission system offers many desirable characteristics representing improvements over conventional coaxial cable used in the transmission of television (video) signals, namely: superior bandwidth, immunity from electromagnetic interference, electrical isolation, small size, light weight, high strength, bendable, corrosion resistant, negligable cross-talk, privacy, transmission properties nearly independent of temperature, humidity, vibration, and potentially lower cost with adequate supply of raw materials. Fiber cables can be readily installed in ducts and conduits with significant savings in space. Intended as a resource statement of technology readiness and potential future implications of fiber optics, this paper briefly describes fiber optic communications by its characteristic major components; mentions some future developments which may have significant impact on broadband communication services; describes some coming trends in communications which may make fiber optic communications very desirable; and discusses and compares some fiber optic communications with existing technology for applications in rural broadband communication systems. (Author/NQ)

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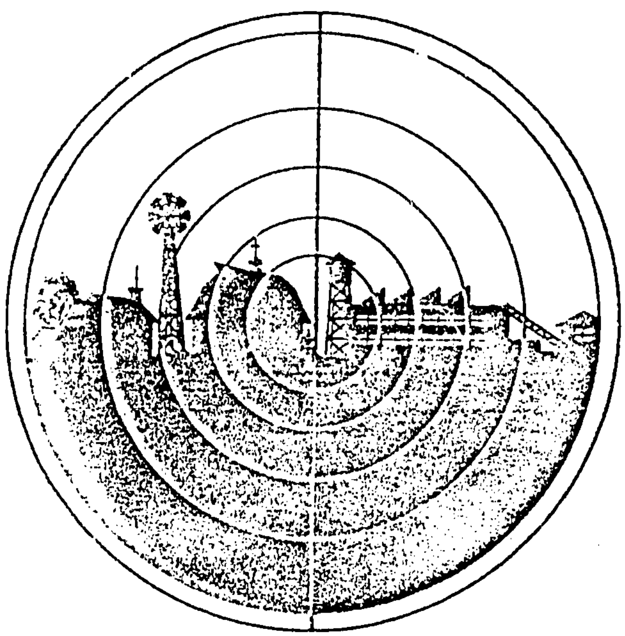

November 15, 16, and 17, 1976

Washington, D.C.

Communications and Rural America

Purpose

In April 1976, the Office of Technology Assessment (OTA) of the U.S. Congress issued a staff report entitled *The Feasibility and Value of Broadband Communications in Rural Areas.* The purpose of the conference is to extend this effort by:

- Considering a broader range of communications technologies which might be used to meet rural needs.
- Further examining the question of whether system demonstrations aimed at achieving economic viability are needed and if so, identifying the kinds of demonstrations which might be undertaken.
- Further examining whether rural interests have been adequately considered in existing Federal communications policy.

The outcome of this effort will be a report incorporating the information and points of view presented at the conference.

Congressional Interest

The conference is being held in response to a request for additional information on rural communications from Senator Herman Talmadge, Chairman of the Senate Agriculture Committee, as approved by the 12 member Technology Assessment Board of the U.S. Congress. Senator Pastore of the Senate Subcommittee on Communications subsequently joined Senator Talmadge in support of the conference. It is intended that the conference will be of value to the U.S. Congress in its deliberations on communications policy.

Conference Dates and Organization

The conference will convene for 3 days, November 15–17, 1976, with about 60 invited participants. For the first 2 days, participants will be equally divided among three panels which will meet in parallel. Each panel will concentrate upon a specific topic addressed in the OTA report as follows:

- Panel 1. Rural Development and Communications.
- Panel 2. Technology, Economics, and Services.
- Panel 3. Federal Policy.

On the third day, participants from all three panels will meet together to exchange and synthesize findings and explicitly address the question of rural system demonstrations.

Cosponsoring Institutions

The National Rural Center is cosponsoring Panel 1 (Rural Development and Communications). The Aspen Institute is cosponsoring Panel 3 (Federal Policy).

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FIBER OPTIC COMMUNICATIONS

TECHNOLOGY

A Status Report

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DISCUSSION PAPER FOR PANEL 2

OTA CONFERENCE ON COMMUNICATIONS

AND RURAL AMERICA

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FIBER OPTICAL COMMUNICATIONS TECHNOLOGY

A Status Report

Foreword

The following paper is submitted for review by panel members participating in the OTA Conference on "Rural Change and Communications". It is intended to serve as a resource statement of technology readiness and potential future implications of the emerging technology of fiber optics. The technology has moved very rapidly from the research and developmental stage to demonstration phases. It has received well deserved publicity in the public press. The author chairs an "Optical Communications Task Force Working Group" entitled "Applications and Users". This interdisciplinary group draws expertise from industry, university and government organizations and interested users from government, industry and national associations of various industries. The viewpoints expressed here are those of the author based on interactions with more than one hundred participants in this Working Group.

Introduction

Fiber optic communications, that is communications over very pure glass transmission channels of diameter comparable to a human hair, is an emerging technology which promises vast improvements in communications capacity at reasonable cost. These tiny waveguides transmit light over distances up to 6 or 8 kilometers without intermediate amplifiers using current technology. The fiber transmission system offers many desirable characteristics representing improvements over conventional coaxial cable used in the transmission of television (video) signals, namely: superior bandwidth (capacity), immunity from electromagnetic interference, no short circuit problems (electrical isolation), small size, light weight, high strength, bendable, corrosion resistant, negligible cross-talk, privacy, transmission properties nearly independent of temperature, humidity, vibration, and potentially lower cost with adequate supply of raw materials (non-copper). The installation of fiber cables should be no more expensive than coaxial cable or twisted-pair conventional telephone type cables. It can be readily installed in ducts and conduits with significant savings in space.

Fiber optic communications is an emerging technology which will be described briefly by its characteristic major components. Some future developments which may have significant impact on broadband communication services will be mentioned. Some coming trends in communications which may make fiber optic communications very desirable will be described. Finally, a discussion and some comparisons of fiber optic communications with existing technology for applications in rural broadband communication systems will be presented.

Technology of Fiber Optic Communications

Since the components necessary to build a fiber optic communication system have been generally developed and manufactured by independent companies in the U.S. (except for one large telephone common carrier), the status of the technology can be most readily described by the salient subsystem components, namely; cables, detectors, sources and connectors. Only limited overall communication sub-system demonstration experience is available at present but factors other than technology readiness, such as resistance to change from proven hardware, will most likely determine the progress of introducing this capability.

Cables

Kao and Hockhan (1966) published a theoretical paper describing the conditions under which optical fibers could be made to transmit light energy with very low loss. Maurer (Kapron, et al., 1970) demonstrated in his laboratory the feasibility of producing optical fibers with these amazingly low losses. Now, only six years later, several manufacturers have commercially available fiber cables with attractive performance capabilities.

Two distinct trends in fiber optic cables have been pursued, namely, bundle and single fiber. Initially, the tiny glass fibers were fragile and the technology required that 60 to 100 fibers be loosely packed inside a plastic cover or sheath to assure a reasonably high percentage of continuous fibers over lengths of a few hundred meters. These bundles were relatively easy to illuminate with low-cost light emitting diode sources which could be readily modulated. This bundle technology has been developed and has proven very useful for short-haul communication links for shipboard and avionics applications.

For these applications which are generally less than 100 meters in length, so-called medium loss fiber bundles (50-100 dB/km) are very useful. Such cables might be used commercially to interconnect terminal devices with computers or central distribution panels in a building such as hospital or school. For distances greater than 100 meters, so-called low-loss (less than 20 dB/km) single fiber cables are required. Such cables are available with 6 to 10 single fibers plus tensile strength members in a protective sheath. The handling and strength properties of such cables approach that of conventional metallic cables. The outside diameter of the resultant cable is about 5 mm. The important parameters of these low-loss cables are attenuation (dB/km) and dispersion (nanoseconds/km). Attenuation determines the signal diminution and dispersion determines the signal distortion. Together, these parameters determine the maximum number of optical pulses per second or the number of channels of information (voice, video, data, facsimile, etc.) which can be transmitted and the maximum distance that the signal can be transmitted without amplification (repeater).

Sources

Electrical signals representing the information to be transmitted (voice, video, data, . . .) must be translated into optical signals which are coupled into the optical fibers for transmission on the system. For relatively low information rates (less than 10 million bits/sec) a light emitting diode (LED), similar to the illumination sources used in many digital watches and hand calculators which have become so popular in the last two or three years, are used. Such sources have been developed and used very successfully with the bundle cable systems. The single fiber cables are capable of handling much higher information rates (500 million bits/sec have been demonstrated) but require a semiconductor laser diode source to provide sufficient optical power at such high information rates and to reduce the difficult coupling of the power into the single fibers. The multi-channel cables can be used as independent channels or as a single channel with redundant paths.

For the extreme bandwidths (information rates) claimed in the popular trade press of 1000 television channels, the only sources available are sophisiticated lasers which at present would have a lifetime of about 200 hours. Such claims are realizable only in future applications. More will be said later on this potential.

Detectors

Relatively simple semi-conductor detectors are available which are readily matched to the fiber cables to detect light energy transmitted by the fiber from the source described above. These photo diode (PIN detectors) devices are well developed and are readily adapted to the bundle cables mentioned above. For the long haul, single fiber cables, so-called avalanche photo diodes (ADP) are desirable because they are much more sensitive than the above diodes. Again, commercially available devices appear to be adequate for many system implementations.

Finally the extreme bandwidths mentioned above require sophisticated (and expensive) detectors called crossed-field photomultipliers which require considerable expertise to operate and maintain. Again such detector applications are not viable for the potential applications envisioned here, at least within the next 10 years.

Connectors

Fiber cables must be spliced, interconnected and coupled to the source and receiver equipments in any actual system applications. Requirements of very strict mechanical tolerances, extreme cleanliness and the need to apply optical craftsmanship to the handling and working of the cables during the splicing and interconnect operations has been particularly challenging especially for the single fiber cables. The industry is rapidly demonstrating ingenious solutions to these technological problems. Other optical components are under development that will permit many drops from a central cable bus to provide local distribution to homes, offices, and independent terminal devices.

Summary of Optical Fiber Technology

Vigorous efforts by many government and industrial laboratories have been directed toward the development of the necessary components to build fiber optic communication links. The basic engineering principles for system design have been published (Gallawa, 1976), trade-off studies to compare cost and operational parameters with conventional technology for various applications have been done (Gallawa, et al., 1975 Straus, et al., 1975), and many communication link demonstrations have been accomplished (Crombie, et al., 1976). A new town project in Japan is underway to use fiber optic communication technology to provide a video information system to some four hundred households (Hollowell, 1975-1976). The current status then for system applications is that the technology is basically ready and demonstrated but system demonstrations are just getting underway.

Future Developments

In looking at the application of broadband communications for new services described in Chapter II of the OTA report (Mills, et al., 1976), there is a menu of several potential services which place varying demands on the communication system. The systems approach recommended that aggregates these many services for distribution on a common broadband network is a departure from past demonstration projects. A design philosophy of meeting the needs of a particular service at minimum cost and with a telecommunication system specifically adapted to that service or the service specifically adapted to an existing telecommunication system has been followed. The concept of looking at the total needs, future potential, and available resources for a rural area and then exercising models to design a system that is economically viable considering total needs and available resources is a commendable approach. In planning such communication systems one should assume that additional innovative services not yet defined will be developed by the user community after a reasonable exposure to the advantages of this new technology. Therefore, special attention should be given to providing adequate capacity where feasible to accomodate future needs.

Some trends in telecommunications that cause fiber optic communication technology to be attractive include the following: 1) Digital communications. The extensive growth of computers and the need for transmission of information already formatted in digital language, is creating changes in telecommunication networks on a world-wide basis. 2) Advanced switching. The application of computers and associated technology (e.g., microcircuitry) in switching, management, and control of wide-band networks make possible the potential delivery of multiple services on a common network as implied by the rural community needs. 3) User Acceptance. The acceptance of new services such as telemedicine requires that the technology be as "transparent" as practicable. That is, the communication system should not create new problems for accomplishing the desired results. Also, the connotation that outdated technology is good enough for lesser developed countries has been rejected in the international marketplace and should not be tried in rural telecommunication experiments in this country; 4) Communications Capacity. The transmission of voice and video signals by digital techniques requires much more bandwidth. For example, a voice channel requires a nominal bandwidth of 4000 Hertz when transmitted in analog form which is used in today's switched network telephone local distribution system. The same signal requires at least 64,000 bits in digital format. Although there is not a one-to-one relation between Hertz and bits per second, the expansion of 16 to 1 is not very misleading. Extensive efforts are being made to lower this bit rate. Similarly, a color television signal requires a nominal 6 million Hertz bandwidth in the present analog transmission format but requires about 90 million bits/second for good quality digital transmission. This indicates that all-digital transmission of the proposed services will require greater bandwidth than current transmission technology is using. The increased volume of digital information in the form of computer communications, facsimile transmission and business communications, which might be called electroni: message services, will require the kind of potential bandwidths offered by fiber optic technology. 5) Direct Reception Satellites. The advent of dedicated small earth terminal satellites at very high frequencies in the electromagnetic spectrum for massive distribution of business, educational, and entertainment services portend extensive use of digital communications, particularly if satisfactory local distribution systems become available. 6) Integrated Optics. Optical communications technology currently in the research phase (e.g., so called integrated optics, optical repeaters, special power sources, optical filtering and switching) clearly promise the potential for super electronic highways capable of assimilating not only the kind of services now on the horizon but will permit the growth and expansion of new terminal devices that will open up new services not now available.

Comparison of Fiber Optics with Existing Broadband Technology

Since no operational fiber optic systems for broadband distribution exist at present, it is difficult to provide quantitative comparisons. A primary reason for this lack of demonstrated capability stems from the cost of the optical cables and components. These high costs in turn, are a result of low production volumes which do not reflect expected economies of scale. For example, current prices on low-loss fiber cable are roughly $2 per channel meter with volume prices dropping to $1 per channel meter for orders reaching 50 km lengths during one year. Projections by responsible representatives of the industry indicate that the price should drop to 30¢ per channel meter in full production quantities. Similar prices for coaxial cable needed for broadband distribution range from $3 per meter required for wideband trunking to .30¢ per meter required for local drops. Copper for the metallic cables and wire will continue to be a diminishing resource and one can expect the costs to continue to rise in the future. Based on raw materials cost at present, the cost of copper necessary to make a 1 kilometer length of shielded twisted pair cable is about $1.50 per kilometer of cable; whereas the cost of glass necessary to produce a similar cable of vastly superior performance characteristics is $0.50 per kilometer. The cabling (packaging) costs of the two is about comparable. The promise of low-cost optical cable rests primarily on the generation of adequate markets to bring about full production.

The cost of cable for rural applications may well be a controlling factor in the selection of the transmission medium because of the distances involved. The costs of switching and control and initial installation costs however, will likely be much greater than the cost of cable and components. The advantages of multichannel fiber cables to provide two-way, wideband (video) capacity as well as independent channels for redundancy, privacy, multiplexing, future expansion, etc. clearly make this technology attractive. The light weight and small size also provide great savings in installation cost and complexity.

Fiber Optics Applied to Broadband Rural Communications

The regulatory requirement of 20 channels for cable television has not proven to be economically viable even in metropolitan areas with high subscriber densities. The installation costs of a cable system, however, make the inclusion of additional channels at the initial installation very desirable. The use of fiber optic distribution systems should make this much more attractive than conventional coaxial systems. The long distance between repeaters in the fiber system should also make it attractive for rural applications just as the use of fiber optics in interoffice trunks for the telephone system is the most attractive first applications in that system.

For really cost effective fiber optic transmission systems, it will be necessary to consider the development of a complete optical system rather than replacing only transmission lines or links in conventional cable systems. The development of computers and terminal devices to accept fiber connections directly rather than through an electronics-to-optics interface should provide economies in the future. Replacement of current television sets with receivers capable of processing only the video information (eliminating the tuner and other amplifier portions of the set) is potentially a very cost effective means of reducing costs. An argument by the manufacturers for not doing this in the past has been the electrical hazard of making connections to the chassis which is connected directly to the 110 volt power source. The use of fiber optics with its total electrical isolation should eliminate this objection.

It is apparent then, that not only should the rural broadband services be designed using a systems approach, but the design of the plant to deliver the services along with the terminal devices that interface with the users should receive similar systems planning.

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