# FIBER-OPTIC DELIVERY OF ADVANCED TELEVISION

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## ABSTRACT

Fiber-optic technology can be expected to play an increasingly important role in TV transport because of its essentially unlimited bandwidth, along with its potential for reducing operating costs and service interruptions. While a variety of fiber-optic TV transport options have been demonstrated in the laboratory and in actual field trials, the principal barrier to advanced TV distribution over fiber is the first-cost of cable installation.

A number of commercial scenarios are discussed which could lead to optical fiber implementation. The technical attributes of fiber-optics and their relevance to advanced TV transport are discussed, as well.

## INTRODUCTION

In just the past 10 years, fiber optics has emerged from a laboratory development to become a major industry, as is evidenced by the more than 50,000 route-miles of fiber-optic long-distance telephone cable in-place in the US, with an additional 20,000 route-miles planned for installation by 1990 [1,2]. It is important to note that although much of the public awareness of fiber optics has focussed on transmission quality and reliability [3], the attribute that has propelled this technology with such unprecedented speed to its critical position in the major arteries of the telephone system is its dramatic reduction of installation and operating costs for telephone service providers. Because of the widespread use of fiber-optic equipment in long-distance telecommunications, the costs of the fiber, cable and certain key components have dropped sharply and there is a clear extension of the fiber system closer and closer to the end-user [4]. In particular, there is intensifying interest of both the cable TV and the telephone industries in utilizing fiber-optics for transport of video signals to their customers.

This paper will describe the attributes of fiber-optic transport, discuss its relevance to advanced television (ATV) signals and explore the prospective issues. An overview of on-going field trials and experimental work will be given, as well.

## ATTRIBUTES OF FIBER-OPTIC TRANSPORT

In fiber-optics, the central core of a glass fiber one-eighth millimeter in diameter carries light signals that are produced by electrically modulating a semiconductor electro-optic device -- generally a laser diode. At the distant end of the fiber these optical signals impinge on semiconductor photodetectors, where they are converted back to electronic signals.

The keys to the technology are the extremely low signal attenuation and the nearly unlimited bandwidth of the glass fiber. In long-distance telecommunications, for instance, these capabilities of optical fibers have enabled commercial transmission at information rates presently as high as 1.7 gigabits per sec ($1.7 \times 10^9$ bps), with repeater spacings of 40km. Such communications trunks carry the equivalent of over 24,000 simultaneous voice channels. An overview of lightwave technology is given in reference [5].

In telephone and data communications over optical fiber, digital techniques have been used exclusively since the signals and the switching in these networks are digital. Additionally, in long-distance communications, digital techniques offer immunity to error build-up as the signal passes through a series of repeater stages. In television production, ABC News has been transmitting segments from its Washington, DC studio to its main operation in New York City over the AT&T fiber-optic telephone network. Digital coding at 45Mb/s is used to make the video signal compatible with the standard telecom DS-3 bit-rate. Bellcore, the research organization of the regional telephone holding companies, is coordinating a nationwide trial for a customer-controllable DS-3 network to distribute contribution-level television signals between broadcasters and affiliates [6]. That trial, which will involve broadcast networks, local and long-distance telephone companies and numerous vendors, is scheduled to begin later in 1988.

Optical fiber has advantages in analog transmission, as well, which in the near term, at least, appears to hold high commercial promise for local delivery of TV signals. The clearest assets of such fiber transport are increased video quality and reliability, along with decreased maintenance costs, since fewer (or no) repeaters are required. In certain cases the installed first cost of a fiber-based system is lower, as well. This is true of the initial service examples: fiber supertrunks from CATV antennas to distribution hubs in Honolulu (Oceanic Cablevision) and Dallas (Heritage Communications). American Television & Communications (Englewood, CO) is making plans to recable one of its urban operations to bring optical fiber backbones from the antenna to several local hubs, with the final delivery to customers by conventional coax. That installation is likely to employ VSB-AM analog signals and one or two low-cost lasers per fiber to deliver approximately 40 NTSC TV channels. Since no subscriber would be more than four (coax) repeater-spans away from the fiber hub, the renewed system is expected to improve the quality and reliability of the delivered TV picture and to reduce maintenance costs.

An additional attraction of fiber for future cable TV systems is the relative ease of upstream transmission in a fiber network, again resulting from the low signal attenuation and the absence of repeaters.

It should be noted that, for the most part, it is anticipated that fiber-optic TV delivery systems will terminate at the home or apartment building. Copper-based cabling is likely to be used within the dwelling units.

Recent developments in fiber-optic systems and devices for telecommunications are reviewed in reference [7]. A brief summary of aspects of fiber delivery of ATV compared with alternative transmission media is given in Appendix 1.

## RELEVANCE OF FIBER-OPTICS TO ADVANCED TELEVISION

It is a well-demonstrated fact that optical fiber technology can provide sufficient transmission bandwidth to permit the emission of a multitude of advanced television signals. In addition, new levels of picture reception quality can be achieved, due to the noise immunity and the low attenuation of fiber-optics. The principal concerns relating to the implementation of fiber-optic local access networks are costs of the electronic and opto-electronic terminating equipment and of the installation of the optical fiber.

Cable installation costs are, of course, the major barrier, especially since copper coaxial cable already exists in much of the country, while fiber installations to residential end-users are only beginning (see Appendix 2). The magnitude of this cost barrier would decrease or possibly even disappear if a coax system is ready for rebuild or, more generally, if the costs eventually required for upgrading copper coax systems to true high definition TV capability turn out to be considerable.

There are indications that -- aside from cable installation -- the first-costs of fiber CATV systems may be commercially tolerable. GTE Laboratories (Waltham, MA) has demonstrated an FM analog system carrying 60 NTSC TV channels with 56dB signal-to-noise on a single 18-km long fiber [8]. The basic technique -- subcarrier multiplexing -- is similar to that used in satellite TV transmission, with the multiplexed microwave (electrical) signal driving a fiber-connected laser, rather than a satellite antenna. At the receiver a photodiode changes the optical signal back to electronic form and a block converter (one per building) shifts the microwave signal down from microwave to RF bands. As in satellite home receivers, an additional converter stage is needed to transform the FM signals to AM [9]. One company has announced low-cost FM-AM converters suitable for cable TV use [10].

Subcarrier multiplexed fiber-optic systems can also transmit information in digital form by frequency-shift-key modulation of a subcarrier. Combined digital and analog transmission has been demonstrated by GTE Labs, as well, which makes this type of optical system compatible with both telephone and cable TV operations. GTE estimates that with subcarrier multiplexing there is sufficient capacity within the 2-6 GHz band to carry 50 analog NTSC channels (2 GHz), 4 digital video channels (800 MHz), 4 HDTV channels (800 MHz) and 25 digital audio channels (200 MHz) -- with 200 MHz remaining for narrowband services, such as voice and data.

A 21-channel digital version of the GTE Labs system is to be part of a planned demonstration by General Telephone in Cerritos, CA, if legal and regulatory concerns can be overcome.

The need for signal security (e.g., scrambling or encryption of pay services) does not appear to raise any distinctive problems for fiber, either in analog or digital embodiments.

## ISSUES RELATING TO FIBER DELIVERY OF ADVANCED TV TO END-USERS

The technical issues relevant to the use of fiber-optics for transport of advanced TV to residential and other end-users will be discussed initially. This will provide some timing context for the commercial issues, which will then be discussed.

### Technical issues

**SYSTEM SELECTION:** As can be seen from the foregoing (and Appendix 2), there are a number of quite different types of systems presently under development and evaluation.

If digital techniques are to be used, there are a number of fundamental system options:

A. Switched star networks, where a limited number of TV signals could be carried simultaneously over the fiber that leads to a given household. The viewer would send a message upstream to request the specific programming to be transmitted. Switched systems are particularly natural for telephone companies, thus a laboratory development and evaluation of a four-channel, 600Mbps switched system is presently underway at Bellcore [11].

B. Multiplexed systems carry all of the TV signals simultaneously, with channel selection done essentially at the TV receiver, as is the case in present coax TV cable systems. Multiplexing can be done either by using different laser wavelengths (wavelength division [12]) or by assigning different time slots (time division [13]) for each TV channel. In the former, tunable filters will be needed; in the latter, very high bit-rate devices will be required.

C. Coherent systems, a special class of multiplexed systems, use heterodyning techniques analogous to those common in radio, but extended to the optical domain. These systems truly access fiber's enormous bandwidth, but will require stable, tunable devices that exist at present only in the form of relatively bulky and expensive laboratory objects [14].

If analog techniques are deemed preferable for ATV delivery, there is still the question of FM vs AM signal type. FM appears to permit a larger number of high-quality channels (appropriate for ATV) to be transmitted, but is not directly compatible with the existing receiver base, if this is required.

**INTERFACES AND STANDARDS:** For digital transmission, three issues must be addressed:

A. What coding/decoding scheme is to be used for fiber transport. This determination is necessary before low-cost codecs can be developed.

B. What are the specific characteristics of the digital bus inside the ATV receiver. Since all of the ATV receivers will be based on digital signal processing, digital transport could be compatible with direct access of the selected TV channel signal to the digital bus.

C. If it is determined that an ATV emission system should be compatible with switched telephone systems, then broadband telecommunications standards are needed, as well, to define the nature of the digital data stream on the fiber.

For analog emission, a receiver interface standard will be needed, perhaps including an FM-to-baseband converter.

## Commercial issues

**COMPETITION:** The principal questions to be resolved are: who will install a fiber-optic TV delivery system and who will provide the TV program services. Regulatory issues aside, both telephone companies and present cable TV companies are capable of installing and operating a fiber-based TV system. Other types of private companies and public utilities could play those roles, as well. Additionally, a telephone company could install and maintain the fiber system, to provide tariffed transport of programs assembled by a "cable TV" company [15].

It is conceivable, as well, that a cable operator could install fiber all the way to end-users. In that event the cable company could provide residences and businesses with alternative access to interexchange carriers (in partial bypass of the local telco). Since telephone companies have traditionally been highly effective at operating and maintaining large, complex, high-quality networks and at providing sophisticated billing functions, however, it might eventually make commercial sense for the cable company either to sell the fiber plant to the telco, with long-term guarantees for transport of the cable company's TV programming or to contract with a subsidiary of the telco for maintenance and billing services. Of course, other scenarios are possible, as well (Appendix 3).

Subsidiary, but critically important questions relate to (1) the regulatory and legal barriers to telephone company involvement in broadband services like TV and (2) the role of broadcasters.

**INVESTMENT:** The installation of fiber-optic local networks nationwide will clearly require major capital investments. It is important to analyze the situation from a national viewpoint to better understand how that investment could be achieved and to determine if significant efficiencies can be obtained. Some facts appear to be emerging:

A. At least two of the regional telephone holding companies (Bell South and Southwestern Bell) have stated publicly that by the early 1990's they expect fiber to be the cost-justified medium for new installations based on basic telephone services only. Thus we can expect that -- even with no other incentives -- local telephone connections by fiber-optics in the US will grow at the new-home rate (1-2 million households per year) beginning in the 1990's.

B. The cost of a fiber over-build to existing end-users, on the other hand, would be justified only if there were reasonable expectations for sufficient additional revenues that would accrue to the phone companies, resulting either from provision of or transport of the new broadband services made possible by fiber-optic systems (e.g., high definition TV, interactive video, video games, video reference services, etc).

C. Thus, if the telephone companies are prohibited from participating in any of these additional revenue opportunities, local fiber telephone networks will grow in the US, but at a relatively slow rate.

D. Other countries are making commitments to install nationwide fiber-optic networks. In particular, NTT of Japan has programmed a national fiber overbuild (at a cost estimated at $80B in 1987); several European countries are building fiber overlay networks. Two aspects of this international effort are particularly threatening to US competitive stature:

In the course of these constructions, considerable technical and commercial expertise will be acquired that will benefit these countries' domestic producers in the massive fiber-optic installations that will be taking place throughout the world during the next two decades.

The inherent operational utility of these nationwide broadband networks will be of great competitive advantage to these countries, as well.

Since any rebuild of the existing copper coaxial cable TV system to permit transport of ATV will entail considerable expenditures, when viewed on a national scale, it is clearly worth investigating the efficacy of applying that same investment toward a US broadband fiber network.

It should be noted that if the telephone companies are barred from providing TV program services, there still remain considerable revenue opportunities for them in other video services, as well as in TV transport. On that basis, fiber overbuilds could be cost-justified. If, on the other hand, telephone companies are denied any revenues from broadband services, then it is likely that for the foreseeable future they will be able to install fiber only for new residential installations and for larger commercial users, thus delaying by decades the availability of an integrated broadband network in the US.

APPENDIX 1: COMPARATIVE SUMMARY OF TRANSMISSION MEDIA FOR ATV

Table 1 lists the basic advantages and disadvantages of each of the alternative media for transmission of ATV signals. In many cases, there will be exceptions to these generalized statements. Thus this appendix should be viewed as merely a starting point in comparative evaluations.

APPENDIX 2: FIBER/TV TRIALS

Telephone companies on three continents have either initiated or announced trials of fiber networks to deliver both telephony and TV signals to residences, as listed in Table 2. In the US trials -- excepting the one case noted -- the telephone company provides only transport of the TV signals from an independent CATV operator.

Table 1. General comparison of transmission media for advanced TV

| **MEDIUM** | **ADVANTAGES** | **DISADVANTAGES** |
|---|---|---|
| BROADCAST | In-place<br>Compatible with installed base of receivers | Spectrum limits<br>Interference<br>Picture quality |
| FIBER-OPTICS ANALOG | High bandwidth<br>Low cost optical components<br>EMI immunity<br>Few, if any repeaters<br>Possible connection to phone system | Little experience<br>Cable installation cost<br>Set-top converter, if FM<br>Limited distance (<20km) |
| FIBER-OPTICS DIGITAL | High bandwidth<br>Noise immunity<br>No noise build-up<br>Easy integration with telephone system<br>Nationwide distrib'n network | Little experience<br>Cable installation cost<br>Higher component costs<br>Needs digital port in ATV receivers, converter for NTSC rcvrs |
| COAXIAL CABLE | Installed cable system<br>Residence access base | Wideband amplifiers<br>Repeater maintenance<br>Noise build-up<br>System reliability |
| SATELLITE (DBS) | Available bandwidth<br>Low-cost electronics | Requires dish antenna<br>Possible power limits |

APPENDIX 3: SCENARIOS FOR IMPLEMENTATION OF FIBER-OPTICS FOR ATV

I. Cable TV company installs optical fiber local distribution network

I-A. Cable company retains ownership and operates system

A local cable franchise holder sees that he will have to make a substantial investment to re-equip his coax system to carry high definition TV with suitable picture quality and a sufficient number of channels. The prospective investment might include new broadband amplifiers, reduction of reflections, possible FM-to-AM converters, etc. He is aware of the long-term promise of fiber-optics and he knows of certain CATV installations where fiber has reduced operating costs and increased customer satisfaction. He decides to invest in fiber, so that he will never again need to upgrade his cable plant.

Because his distribution is repeaterless, he is able to offer bidirectional services [16], such as interactive video, for his customers by providing a point-of-presence for an interexchange carrier on his network. He receives additional revenue from this extra capability and his customers enjoy new forms of recreation, communication and learning.

I-B. Cable company sells the fiber system to the local telephone company, with lease-back agreement for transport of CATV signals

The local telephone company sees an opportunity for additional new revenues in broadband services over its switched net-

Table 2. Fiber to-the-home trials that include video services

| Telephone company | Location | Equipment supplier | Start date | Comments |
|---|---|---|---|---|
| **UNITED STATES** | | | | |
| Southern Bell | Hunters Creek, FL (Orlando area) | | 1987 | New housing devel; Switched CATV |
| Southern Bell | Heathrow, FL (Orlando area) | Northern Telecom | 3/89 | Upscale new devel; 3 simult TV chnls, 54 chnls avail, ISDN |
| General Telephone | Cerritos, CA (5000 units) | GTE, others | late'88 | 20 chnl CATV transport; Video-on-demand* |
| Bell of Pa. | (New develm't, 2000 units) | Alcatel Sitcom | | Multimode fiber, LED's for local drop |
| **OTHER COUNTRIES** | | | | |
| MITI (Japan) | Higashi-Ikoma | NEC,Hitachi others | 1978 | HI-Ovis; 2-way |
| Bell Canada | Yorkville, Ont | No. Telecom | 1978 | Multimode fiber |
| Manitoba Tel (Can) | Ste Eustache & Eli, Manitoba | No. Telecom | 1981 | Canadian Dept of Communications |
| Deutsche Bundespost (W. Germany) | 6 major cities | Siemens,SEL others | 1983 | BIGFON; fiber overlay |
| France Telecom | Biarritz | SAT | 1984 | Includes 2-way video |

* Planned by General Telephone, subject to regulatory approval.

work, but it knows that these revenues cannot support the construction of a second fiber network in the locality. It offers cash to the CATV operator, takes over the operating and maintaining of the physical network, provides a long-term agreement to the cable company for transport of the TV signals to his customers, and includes billing and collection services. The cable operator ends-up with a television business without many of the headaches; the telephone company obtains a fully-connected fiber loop plant [17].

## II. The local telephone company builds and operates the fiber network

### II-A. Telco provides only transport of television signals

Legal and regulatory barriers may continue to prohibit telco's from providing broadband services, but the transport of such services over a telco's fiber network at tariffed rates may be permitted. Thus, if a tariff can be established that is attractive to the local broadband and cable TV service providers, a fiber overbuild (or a partial overbuild, such as fiber supertrunks) by the telco may be justifiable. The telco is more likely than a CATV company to have the large financial resources for such an investment, but its local regulators will need to be convinced that the investment will not burden the basic telephone ratepayers. Fiber delivery of high definition TV and other broadband services could provide that justification.

It is important to note that -- once a telephone company provides a broadband pathway between its residential customers and the national public network -- then a number of programming providers (e.g., premium entertainment channels, motion picture studios, even TV networks) can sell programming directly to these households by a dial-up telephone connection. Needless to say, this would radically change the nature of the "cable TV" industry.

### II-B. Telco's are permitted to provide broadband services

If there are no restrictions on the services that can be delivered by the telephone company, then it should be able to justify the costs of the fiber network installation. This would result either in head-to-head competition with the local CATV operator, possibly including double network builds, or some accommodation between the two parties. In this scenario, it is difficult to envision self-supporting roles for all three of the present participants: broadcasters, cable operators and telco's.

## III. Alternative network implementers

There are other industries or individuals who could possibly start construction of fiber local networks. Included among these would be:

Local private service companies and utilities (electric companies, teleports)

Private investors, forming a "new industry"

Broadcasters, not wanting to allow themselves to be closed out from the opportunities in true high definition TV.


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## REFERENCES


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2. Generally, each of these cables carries from 24 to 36 fibers.

3. Telephone companies guarantee bit error rates one-thousand times better on fiber routes that on copper.

4. Many major industrial plants and corporate offices are already connected directly by fiber to public and private networks. In lower and midtown Manhattan, fiber loops are in operation both by New York Telephone, the local phone company, and by independents.

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9. Of course, such converters will not be necessary with future "cable-ready" TV receivers that have baseband analog and/or digital interfaces.

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13. P. R. Prucnal, et al, "Ultrafast all-optical synchronous multiple access fiber networks", IEEE J. Selected Areas Commun., SAC-4, p.1484-1493, (1986)

14. B. S. Glance, et al, "WDM coherent optical star network", J. Lightwave Technol., 6, p.67-72 (1988)

15. In Cleveland, Ohio the cable TV system is being installed by Ohio Bell, the local telephone company, according to the system implementation plan of a cable TV MSO (Viacom), with eventual purchase or lease-back of the system to a group of local investors who hold the cable TV franchise.

16. It must be pointed out that these interactive services could not be provided in a fiber system configured in the conventional CATV tree-and-branch architecture with passive taps -- some form of switching would be required.

17. In order for this system to be potentially attractive to the telco, it would have had to have been constructed to some approximation of telephone company standards, including, for instance, at least the provision for controlled environment vaults at major junctures.