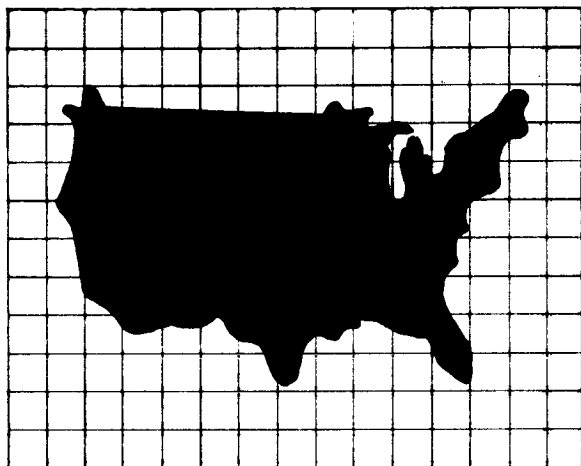


U.S. LONG DISTANCE FIBER OPTIC NETWORKS: TECHNOLOGY, EVOLUTION AND ADVANCED CONCEPTS



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**U.S. LONG DISTANCE
FIBER OPTIC NETWORKS:
TECHNOLOGY, EVOLUTION
AND ADVANCED CONCEPTS**

VOLUME II
Fiber Optic Technology
and Long Distance
Networks

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U.S. LONG DISTANCE FIBER OPTIC NETWORKS:
TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

VOLUME I:

FIBER OPTIC TECHNOLOGY AND LONG DISTANCE NETWORKS

Table of Contents

	<u>PAGE</u>
SUMMARY	1
INTRODUCTION	2
1.0 OVERVIEW OF FIBER OPTIC TECHNOLOGY	5
1.1 Description of Fiber Optics Systems	5
1.2 Advantages of Fiber Optics for Long-Haul Transmission	7
1.2.1 Bandwidth	7
1.2.2 Low Attenuation	9
1.2.3 Size and Weight	9
1.2.4 Immunity from Interference	10
1.2.5 Security	10
1.2.6 Compatibility with Digital Technology	10
1.2.7 Reliability	10
1.2.8 Modular Design	10
1.2.9 Ease of Installation	11
1.3 The Historical Development of Fiber Optics	11
1.3.1 Three Generations of Fiber Optics	12
1.4 Fiber Optics Technology: State-of-the-Art and Future Trends	13
1.4.1 Greater Bit Rate and Bandwidth	13
1.4.2 Longer Transmission Distances	14
1.4.3 Move to Longer Wavelengths	16
1.5 Factors Affecting Fiber Optics Development	18

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III IV

2.0	FIBER OPTIC COMPONENTS FOR LONG-HAUL SYSTEMS	19
2.1	Introduction	19
2.2	Optical Fibers	19
2.2.1	Types of Fibers	20
2.2.2	Fiber Materials	22
2.2.3	Attenuation	22
2.2.4	Dispersion Factors Limiting Bandwidth	28
2.2.5	Research and Development Foci	29
2.2.5.1	New Fiber Materials	29
2.2.5.2	Production Processes	32
2.2.5.3	Dispersion Shifted and Dispersion Flattened Fibers	32
2.2.6	Optical Fiber Prices	34
2.2.7	Suppliers	34
2.2.8	Forecasts	34
2.2.8.1	Bandwidth	34
2.2.8.2	New Fiber Materials	37
2.3	Cables	38
2.3.1	Research and Development Foci	38
2.3.1.1	Longer Cable Lengths	39
2.3.1.2	Number of Fibers in Cable	39
2.3.2	Splicing	40
2.3.3	Cable Prices	41
2.3.4	Suppliers	41
2.3.5	Forecasts	41
2.4	Light Sources	43
2.4.1	Requirements for Light Sources	43
2.4.2	Laser Characteristics and Trends	43
2.4.2.1	Bandwidth and Bit Rate	44
2.4.2.2	Wavelength	45
2.4.2.3	Spectral Width	45
2.4.2.4	Launching Power	45
2.4.2.5	Beam Shape	47
2.4.3	Research and Development Foci	48
2.4.3.1	Distributed Feedback Lasers	48
2.4.3.2	Production Processes	49
2.4.3.3	Use of LEDs with Single Mode Fiber	49
2.4.3.4	Higher Power Output	50
2.4.3.5	Reduced Drive Current	51
2.4.4	Light Source Prices	51
2.4.5	Suppliers	52
2.4.6	Forecasts	52

2.5	Detectors	54
2.5.1	Research and Development Foci	54
2.5.1.1	New Materials	54
2.5.1.2	Coherent Communications	56
2.5.2	Detector Prices	58
2.5.3	Suppliers	58
2.5.4	Forecasts	61
2.6	Multiplexers	62
2.6.1	Electronic Multiplexing	62
2.6.2	Wavelength Division Multiplexing	62
2.6.3	Research and Development Foci	65
2.6.4	Forecasts	65
2.7	Switching	67
2.8	Summary of Technology Elements	68
3.0	FIBER OPTIC LONG-HAUL SYSTEMS	70
3.1	Overview	70
3.2	The Impact of Divestiture and Deregulation	70
3.3	The Use of Fiber Optics in Long Haul Networks	70
3.4	Market Trends and Issues	77
3.4.1	Consolidation	77
3.4.2	First-in-Ground Factor	80
3.4.3	Overcapacity	81
3.4.4	Rights-of-Way	82
3.4.5	Exploitation of Secondary Markets	83
3.5	Forecasts	84
4.0	FIBER OPTIC LONG-HAUL NETWORKS	86
4.1	National Networks	86
4.1.1	ALC Communications	86
4.1.2	AT&T Communications	86
4.1.3	Fibertrak	93
4.1.4	MCI	96
4.1.5	National Telecommunications Network	99
4.1.6	U.S. Sprint	103

4.2	Regional Networks	106
4.2.1	Bandwidth Technologies	106
4.2.2	Consolidated Network	106
4.2.3	Digi-Net	108
4.2.4	Electra Communications	111
4.2.5	Indiana Switch	113
4.2.6	Institutional Communication Corporation	116
4.2.7	LDX Net	118
4.2.8	Lightnet	120
4.2.9	LiTel	124
4.2.10	Microtel	126
4.2.11	Mutual Signal	128
4.2.12	NorLight	130
4.2.13	Rochester Communications, Inc.	132
4.2.14	SouthernNet	135
4.2.15	Southland Fibernet	136
4.2.16	Wiltel	138

EXHIBITS

1.1	Basic Long Haul Fiber Optic System Design	6
1.2	Increasing Transmission Rates of Fiber Optic Systems	8
1.3	Repeater Spacings, Bit Rate and Technology Trends	15
1.4	The Trend to Longer Wavelengths	17
2.1	How Light Rays Travel in Three Fiber Types	21
2.2	Causes of Attenuation	23
2.3	Relationship Between Wavelength and Absorption	24
2.4	Spectral Transmission Loss for Single Mode Fiber	25
2.5	Characteristics of Fibers	26
2.6	Progress in Fiber Attenuation	27
2.7	Effects of Dispersion on Signal	28
2.8	Reduction of Optical Fiber Losses	31
2.9	Price Trends of Single Mode Fiber	35
2.10	1985 U.S. Fiber Production	36
2.11	Single Mode Fiber Performance	36
2.12	Average Fiber Count for Selected Long Haul Networks	40
2.13	Estimated Cable Shipments	42
2.14	Spectral Widths of Lasers and LEDs	46
2.15	Output Power and Drive Current of Sources	47
2.16	Beam Shape of Light Sources	48
2.17	LED/Single Mode Fiber Experiments	50
2.18	Spectral Response of Detector Materials	55
2.19	Heterodyne Coherent Communications	57
2.20	Price Trends of APD Detectors	59
2.21	Price Trends of PIN Detectors	60
2.22	Wavelength Division Multiplexing	64
3.1	Existing and Proposed Fiber Optic Networks	71
3.2	Shift of Transmission Media for Two Major Networks	74
3.3 through 3.6	Fiber Optics System Growth in the U.S.	75
3.7	Consolidation of Long Haul Fiber Optics Networks	78

4.1	ALC Network	87
4.2	AT&T Lightwave Network Plan, 1982	89
4.3	AT&T Domestic Digital Network, 1990	90
4.4	FT3C Lightwave System Northeast Corridor	91
4.5	Pacific Corridor Project	92
4.6	Proposed Fibertrak System	94
4.7	MCI's Nationwide Network	97
4.8	MCI's Lightwave Systems	98
4.9	National Telecommunications Network	101
4.10	National Telecommunications Network Status Report	102
4.11	U.S. Sprint Network	104
4.12	Bandwidth Technologies Route Map	107
4.13	Consolidated Network	109
4.14	Digi-Net System Map	110
4.15	The Electra Network	112
4.16	Indiana Switch Route Map	115
4.17	ICC Fiber Optic Network	117
4.18	LDX Net Fiber Optic Network	119
4.19	Lightnet's Fiber Optic Network	122
4.20	LiTel's Fiber Optic Network	126
4.21	Lasernet Network Topology	128
4.22	Mutual Signal's System	130
4.23	NorLight Fiber Network	132
4.24	RCI's Intercity Network	135
4.25	SouthernNet Route Map	136
4.26	Southland Fibernet Route Map	138
4.27	The Wiltel Network	140

U.S. LONG DISTANCE FIBER OPTIC NETWORKS:
TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

Summary

Over the past two decades, fiber optics has emerged as a highly practical and cost-efficient communications technology. Its competitiveness vis-a-vis other transmission media, especially satellite, has become a critical question.

This report studies the likely evolution and application of fiber optic networks in the United States to the end of the century. The outlook for the technology of fiber systems is assessed and forecast, scenarios of the evolution of fiber optic network development are constructed, and costs to provide service are determined and examined parametrically as a function of network size and traffic carried.

Volume I consists of the Executive Summary.

Volume II focuses on fiber optic technology and long distance fiber optic networks. Among the volume's conclusions are: fiber optic technology is still a young technology, with improvements yet to be realized in performance and cost; fiber optics is the preferred medium for many long distance applications; many companies have been investing heavily in long distance fiber optic networks, raising fears of a capacity glut.

Volume III develops a traffic and financial model of a nationwide long distance transmission network. A LATA-to-LATA traffic matrix is established and then applied to four long distance backbone network configurations with 11, 15, 17, and 23 nodes. The model is then extended to include transmission from the inter-exchange backbone network to the points-of-presence in individual LATAs. Cost calculations are done for first and annual costs for all four network configurations and for projected traffic from 1985 to 2000. Cost drivers are identified for various levels of the total network.

Among the study's most important conclusions are: revenue requirements per circuit for LATA-to-LATA fiber optic links are less than one cent per call minute; multiplex equipment, which is likely to be required in any competing system, is the largest contributor to circuit costs; the potential capacity of fiber optic cable is very large and as yet undefined; and fiber optic transmission combined with other network optimization schemes can lead to even lower costs than those identified in this study.

U.S. LONG DISTANCE FIBER OPTIC NETWORKS:
TECHNOLOGY, EVOLUTION, AND ADVANCED CONCEPTS

INTRODUCTION

Background

Over the past two decades, fiber optics has emerged as a highly practical and cost-efficient communications technology. With potentially unlimited bandwidth, low attenuation, small size and weight, immunity from interference, and other advantages, fiber optics has competed with, and often displaced, other communications media in a number of applications. Long distance telecommunications networks are one area in which fiber optics has proven to be especially competitive.

Proper guidance of NASA's advanced communication satellite technology program requires an understanding and assessment of competing transmission systems such as fiber optics. Only through a comprehensive assessment of these technological alternatives can the most productive direction for satellite technology development be determined.

To assist them in their evaluation, NASA Lewis Research Center contracted with IGI Consulting to study the likely evolution and application of fiber optic networks in the United States to the end of the century. According to the scope of work,

The outlook for the technology of fiber systems will be assessed and forecast, scenarios of the evolution of fiber optic network development will be constructed, and costs to provide service will be determined and examined parametrically as a function of network size and traffic carried. This information will provide a quantitative data base for the Phase II study which will directly study the impact of fiber networks on communications satellite systems.

This report is the result of that 14-month study effort.

Organization of The Study

This study is presented in three volumes.

Volume I is the Executive Summary, which provides an overview of the methodology, results, and conclusions of the entire effort.

Volume II focuses on "Fiber Optic Technology and Long Distance Networks."

- Section 1 provides an overview of fiber optic technology. Its principal subsections present a description of fiber optic systems, the advantages of fiber optics for long haul transmission, the historical development of fiber optics, trends in fiber optic technology, and factors affecting the development of the technology.
- Section 2 discusses performance characteristics, research and development foci, costs, and technology assessments for each of the major components required for long distance fiber optics networks: fibers, cables, light sources, detectors, multiplexers, and switches.
- Section 3 introduces fiber optic long haul systems and provides the background necessary to understand the phenomenal growth of these networks over the past several years. Among the issues discussed are the impact of divestiture and deregulation, the use of fiber in long distance networks, and market trends such as consolidation, overcapacity, and rights-of-way.
- Section 4 presents descriptions, route maps, and technology and market assessments for 22 national and regional fiber optic long haul networks. The national systems presented are ALC Communications, AT&T Communications, Fibertrak, MCI, National Telecommunications Network, and U.S. Sprint. The regional networks are Bandwidth Technologies, Consolidated Network, DigiNet, Electra Communications, Indiana Switch, ICC, LDX Net, Lightnet, LiTel, Microtel, Mutual Signal, NorLight, Rochester Communications, SouthernNet, Southland Fibernet, and Wiltel.

Volume III develops a financial model of a nationwide long distance transmission network between local access and transport areas (LATA). This network uses optical fibers as the transmission medium and is capable of carrying the total domestic inter-exchange (IX) traffic.

- Section 5 establishes the traffic model upon which the financial model is based. Based on both switched telephone traffic and private line services, the model creates a LATA-to-LATA traffic matrix for the total switched IX telephone traffic. The data from this matrix are then applied to four long distance backbone network configurations consisting of 11, 15, 17, and 23 nodes. The numbers of voice circuits needed on each

link connecting the access nodes of the backbone networks are then calculated. The model is also extended to analyze the regional access networks associated with each access node in each of the four IX backbone networks, i.e., the model includes transmission from the inter-exchange backbone network to the carrier's point-of-presence (POP) in the individual LATA.

- Section 6 provides the financial model for the four networks established in Section 5. This model establishes the costs of material and equipment, engineering, installation and testing so that a system cost analysis can be conducted for any network configuration and for projected traffic from 1985 to 2000. Cost calculations are carried out for first costs and annual costs. The model is divided into two major segments -- the inter-nodal and the LATA access -- for each prototype network. Each model segment is evaluated and analyzed separately, and the results are combined, making it possible to identify the various cost drivers and to note their effect on various levels of the total network.
- Section 7 presents summary statements about the evolution and impact of fiber optic networks. Comparisons are made between fiber optics, microwave, and satellites. Conclusions are also drawn concerning the current and potential capabilities and costs of fiber optic long distance networks.

SECTION 1.0
OVERVIEW OF FIBER OPTICS TECHNOLOGY

1.1 DESCRIPTION OF FIBER OPTICS SYSTEMS

Fiber optics involves the transmission of light through a glass filament. Unlike conventional copper systems which transmit electro-magnetic waves through a dielectric medium, fiber optic systems transmit modulated light waves through an optical waveguide. Because of the nature of the light sources and fibers, optical systems favor the transmission of information using a digital format. The digitized and modulated signal is fed to a laser or light-emitting diode (LED), which emits corresponding modulated light signals. These signals travel along a hair-thin fiber at nearly the speed of light and are detected by a diode receptor at the other end. On reaching their destination, the lightwaves are then reconverted back to sounds, data and/or images and are processed by conventional techniques. The development of fiber optic technology has been synergistically helped by advances in a number of related sciences - microprocessing, large-scale integration, and software.

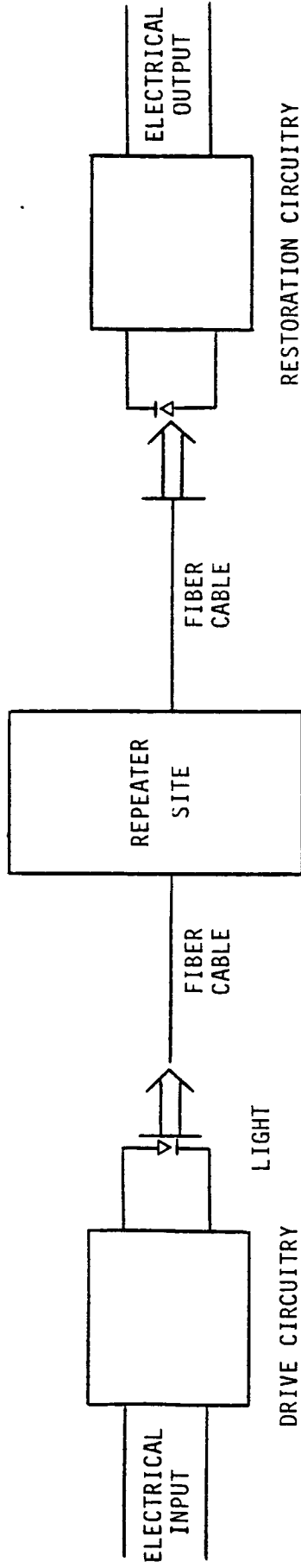
Exhibit 1.1 shows the outlines of a basic fiber optic system. Regardless of the use to which it may be put, the basic elements are the same:

- conversion and modulation electronics and a light source;
- a transmission medium, consisting of an optical cable with one or more fibers;
- repeater sites as required to regenerate the lightwave signal over long spans;
- a light detector and receiving electronics;
- methods of connecting optical fiber cables to the electronics; and
- splicing.

This is only a simple point-to-point block diagram; more complex systems are possible using optical switches, couplers, etc. This very simplified outline of a fiber optic system does not, of course, imply a simple or stagnant technology. Rather, it indicates that we are now at an early stage in the development and application of the technology.

EXHIBIT 1.1

BASIC LONG HAUL FIBER OPTIC SYSTEM DESIGN



1.2 ADVANTAGES OF FIBER OPTICS FOR LONG HAUL TRANSMISSION

1.2.1 Bandwidth

Bandwidth, or the amount of information that can be sent over a transmission medium, has always been regarded as a scarce resource. The dots and dashes of early telegraphy could transmit only one message at a time. The first telephone could also send only one voice circuit, although at the faster rate of normal speech. Since then, progress in telecommunications has entailed advances in the amount of signal (whether analog or digital) that can be transmitted over a medium. Coaxial cable, microwave, satellites, multiplexing, digital compression -- all of these technologies have been developed to increase the amount of information that can be transmitted simultaneously over a path.

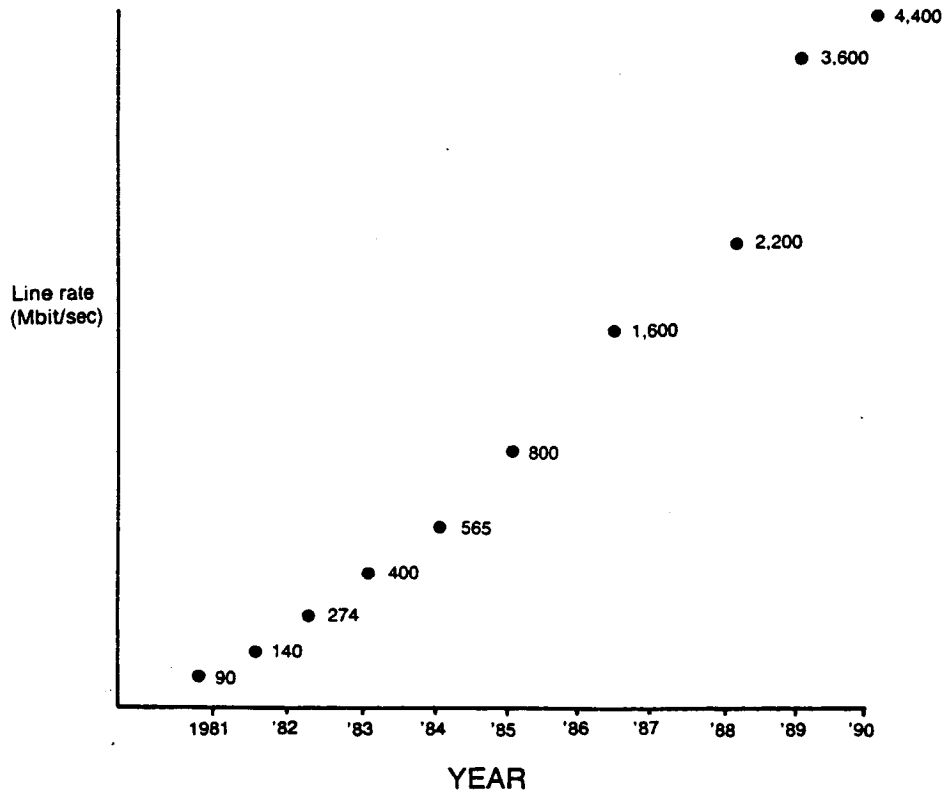
Yet despite the development of new technologies, there has always been a demand for larger volumes of information to be transmitted at lower cost. Each new transmission technology has expanded the capabilities of communications networks and the types of services that could be offered. This has proven to be particularly important with the development of new wideband services -- e.g. high-speed facsimile and video teleconferencing -- that require large amounts of bandwidth.

By contrast, fiber optics has the potential to offer immense bandwidth. In the late 1970s, optical systems were capable of transmitting at the rate of 45 megabits per second (Mbps), or the equivalent of 672 voice channels per fiber. Present systems routinely operate at 565 Mbps, or 8064 voice channels. By 1987, commercially-available systems will transmit at 1.7 billion (giga) bits per second (Gbps). As shown in Exhibit 1.2, the trend has been a doubling of line transmission rates every year. While this rate of increase will slow, significant gains in bit rates and bandwidth can continue to be expected. Reports from research laboratories indicate the realization -- and eventual commercialization -- of terabit systems, or trillions of bits transmitted per second.

The knowledge that a pair of optical fibers can transmit many billions, and even trillions, of bits per second must be coupled with the realization that cables currently contain up to 156 fibers; cables with even more fibers are also, of course, possible. Techniques are being developed that will allow a single fiber to transmit light in both directions (duplex operation). In addition, each fiber at present carries light signals of only one wavelength, and requires two fibers for duplex operation. In the future, wavelength-division multiplexing could allow signals of several tens to hundreds, potentially thousands, of wavelengths to be transmitted simultaneously over a single fiber pair.

EXHIBIT 1.2

The Increasing Transmission Rates of Fiber Optic Systems



Trillions of bits per wavelength times hundreds of wavelengths per fiber times hundreds of fibers per cable -- for the first time, engineers and network designers are facing the prospect of unlimited bandwidth. This "scarce resource" is on its way to becoming a virtually limitless commodity at negligible transmission cost, and the possibilities for new applications, architectures, and services are awesome.

1.2.2 Low Attenuation

In contrast to longer-wavelength radio signals traveling through other media, which must be boosted every few to tens of kilometers, recent advances in lightwave technology allow for experimental transmission over several hundred kilometers without repeaters. Glass fibers have moderately low losses (2-3 dB/km) in the 800-900 nm "first window" range, lower losses near 1300 nm (0.4 dB/km), and lowest losses of all at the 1550 nm "third window" (0.2 dB/km). The 1300-1500 nm range is the "long wavelength" region for optical communications, and is the range at which long haul systems operate.

This low attenuation makes fiber an excellent medium for long-distance routes, and serves to explain why so many of the new and established long-haul carriers are scrambling to construct fiber optic networks. Upcoming generations of undersea telecommunications cables will also be fiber optic.

As is the case with bandwidth and many of the other advantages outlined here, the low attenuation offered by optical fibers now has not nearly reached its limit. The use of longer wavelengths (2 to 10 microns) and the development of new low-loss heavy metal fluoride fibers promise unrepeated distances of thousands of kilometers in the more distant future.

1.2.3 Size and Weight

The greater carrying capacity of optical fibers is accompanied by a smaller size. A copper coaxial cable carrying 36,000 channels has a diameter of 7.5 centimeters and weighs 11.0 kilograms per meter. By contrast, a fiber cable carrying 50,000 channels is only 1.25 centimeters in diameter and weighs just 1.2 kilograms per meter. In urban environments especially, where duct congestion presents a major problem, the smaller size of optical cables offers significant advantages.

Long distance network operators find that the smaller size and weight offer greater design flexibility in long haul applications. Cable has been installed along bike paths, inside oil pipes, along railway roadbeds, and in underground conduits.

1.2.4 Immunity from Interference

Optical signals are immune from lower-frequency electromagnetic interference from sources such as lightning, crosstalk, motors, or power lines. They also exhibit stability in high temperature environments. This makes lightwave systems extremely desirable in a variety of industrial and military applications.

1.2.5 Security

It is difficult to tap into a glass fiber without detection. This feature makes fiber an ideal medium for applications requiring confidentiality and security.

1.2.6 Compatibility with Digital Technology

The telephone network was originally designed to transmit the human voice in analog form, i.e. as continuous and modulated waves of electromagnetic energy. For decades, this was perfectly adequate as voice communication was viewed as the primary, if not only, use of the telephone network. Twenty years ago, digital transmission for short hauls (up to 100 miles) was introduced because of lower costs achieved through integrated digital circuits, but most of the telephone network remained analog. Now, more digital transmission and switching facilities are being implemented to handle growing data communications traffic. As digital networks are increasingly implemented, ISDN standards in corporate and residential settings will become adopted. Fiber optics' electronic components are most cost-effective in digital implementation, and fiber optics will be more desirable for high-volume digital transmission.

1.2.7 Reliability

Offering greater reliability and requiring less maintenance than other transmission media, fiber optic components and systems have longer operating lives. LEDs, for example, can operate without faulting for a million hours, the equivalent of over one hundred years. Because optical systems use fewer repeaters, there are fewer sources of failure, thereby resulting in enhanced reliability.

In long haul systems, this advantage is especially important, as repairing a failing component can be an expensive and time consuming project, particularly if it is located in a remote spot.

1.2.8 Modular Design

Each component of a fiber optic system can be upgraded individually, without the need for an overhaul of the entire network. The technical capabilities of the fibers installed

today will be adequate for components, such as faster lasers, that are not yet developed or commercially available. New techniques such as wavelength-division multiplexing can also be instituted without a change in the cable infrastructure.

1.2.9 Ease of Installation

Although splicing and connecting optical cable at one time presented a major hurdle, the barrier has been largely overcome. New cable and connector designs have made for more routine installation, and a new generation of trained personnel is acquiring the necessary expertise.

1.3 HISTORICAL DEVELOPMENT OF FIBER OPTICS

Historians of optical communications differ in their assessment of when the use of light for communications purposes can be said to have had its start. One source, stretching things a bit, finds antecedents of optical communications in the relay of fire beacons that brought Queen Clytemnestra news of the fall of Troy.

More plausibly, nineteenth-century work by John Tyndall on refraction and reflection, and by Charles Vernon Boys on drawing glass fibers, are often cited as important precursors to the development of fiber optics. Alexander Graham Bell's invention of the "photophone" in 1880 is also touted as the start of optical communications, although one suspects its notoriety to be due less to its significance as a true precursor to modern fiber optics technology than to the name recognition accorded its inventor.

By most accounts, fiber optics began in 1966, when a clear case for the use of optical waveguides was made in a landmark paper by K. C. Kao and G. A. Hockham of ITT's Standard Communications Laboratories. In their article in Proceedings of the IEE, the two researchers argued that communications over a glass optical fiber would be practical if attenuation losses could be reduced to 20 dB per kilometer.

It was not until 1970 that Corning announced the production of a fiber that had broken the 20 dB barrier. By 1972, losses were down to 4 dB/km in laboratory samples. Since then, the attenuation rate for silica fibers have reached the theoretical limit of 0.15 dB/km.

The search in the early 1970s for a viable fiber production technology led in 1975 to the development of the chemical vapor deposition technique for making silica graded-index multimode fiber. Among its characteristics were a 2-3 dB/km attenuation at 850 nm, and dispersion values of around 1 ns/km-nm. Its

relatively large 50 micron core diameter led to relatively easy splicing and connectorization.

The availability of a viable transmission medium, along with the invention in 1970 of a reliable laser light source, provided both the components and impetus needed for continuous and rapid progress in optical communications.

The progress made by fiber optics over the past two decades has been nothing short of phenomenal. Microwave radio took 20-to-25 years to evolve into a position of prominence in the telecommunications industry. Satellite and T-carrier each took 10-to-15 years to achieve its own technical sophistication and niche. Fiber optics, on the other hand, has become the pre-eminent communications technology in less than a decade.

From a theoretical possibility twenty years ago, the technology has spawned an industry that is approaching a value of one billion dollars in the United States alone. The development of optical communications has been characterized by steady progress in a number of areas, including bit rates, unrepeated distances, materials used, and range of applications.

1.3.1 Three Generations of Technology

From the vantage point of twenty years of "historical" perspective, it is possible to discern the evolution of fiber optics through three generations of technology.

The first generation consisted of components and systems operating at "first window" wavelengths of around 850 nanometers (nm) transmitted through step-index fibers. With only one index-of-refraction boundary between the cladding and the core, these fibers provide for a number of pathways of light reflection. In combination with the large core, which allowed for the propagation of many modes, this fiber structure meant that modes of different orders reached the other end of the fiber at different times, resulting in undesirable pulse spreading. It was also discovered that operation at 1300 nm could eliminate material dispersion and could thereby reduce attenuation levels to less than 0.5 dB/km.

The second generation entailed the shift to multi-mode graded-index fibers and 1300 nm "second window" wavelengths. Graded-index fibers also have wide diameters (allowing for easy connectorization), but they have many layers of cladding with progressively decreasing refractive indexes. Since high-order modes have a faster average velocity than low-order modes, all modes tend to arrive at the same time. This results in modal dispersion of under 10 ns/km-nm compared with up to 40 ns/km-nm for multimode step-index fibers. The use of graded-index fibers at longer wavelengths resulted in attenuation of between 0.8 and

1.5 dB/km, allowing for transmission of up to 20 kilometers.

The third and present generation consists of single-mode fibers operating at wavelengths of up to 1550 nm. The advantage of single-mode fiber is that its smaller core diameter (typically 2-10 microns) allows only one mode to propagate in the fiber, thereby limiting attenuation due to modal dispersion. This allows for much greater bandwidths and lower attenuation.

While the third generation represents the present state of the art, technology from all three generations have found their niches in various applications. Short-wavelength transmission over multimode fiber, for example, is still widely used for data communications over short distances, primarily because of the lower-cost sources and detectors.

And, of course, research and development is still progressing on all aspects of optical communications. Researchers are now developing a fourth generation of coherent technology that operates at wavelengths of 1550 to 1500 nm. A fifth generation, with transmission wavelengths of up to 10,000 nm are also envisioned. Both of these generations will entail the development and commercialization of new light sources, fibers, and materials.

1.4 FIBER OPTIC TECHNOLOGY: STATE-OF-THE-ART AND FUTURE TRENDS

Although progress is continuing rapidly on a dizzying number of fronts, there are three areas of technological development that can provide indicators of overall system performance. These parameters constitute foci of activity through which researchers are extending the boundaries of performance and the state of the art. They are:

- Greater bit rate and bandwidth
- Lower attenuation
- Move to longer wavelengths

1.4.1 Greater Bit Rate and Bandwidth.

As has been the case throughout the history of telecommunications, the trend in optical communications has been toward higher bit rates and greater bandwidth. It was only in 1978 that NTT, in an heroic experiment, reported transmitting 800 Mbps over an 8-kilometer span and 32 Mbps over a 54-kilometer link. Today's championship results are on the order of 2.4 gigabits over 32 kilometers (British Telecom, February 1986), 8 gigabits over 68.3 kilometers (Bell Labs, February 1986), and 1.6 gigabits over 120 kilometers (NTT, April 1986).

As was illustrated in Exhibit 1.2, there has been a steady and rapid rise in the transmission speed of optical systems. Historically, bit rates have doubled every year.

Long-distance networks presently operate at 405 Mbps or 565 Mbps. On May 8, 1986, MCI announced that it would upgrade its 40-mile single-mode link between Manhattan and White Plains to 810 Mbps. Although only one fiber pair will be upgraded initially, a spokesman from MCI indicated that more 810 Mbps links will be added as equipment becomes available. AT&T has made it widely known that they will commercialize 1.7 Gbps technology in 1987.

There is still a long way to go before the theoretical limits of transmission speed are reached. Optimistically, bit rates may continue to double every year, but that seems unlikely. Like the legendary Chinese peasant whose one grain of corn from the king doubled every day for a month and made him a rich man, a yearly doubling of bit rates would lead to phenomenal speeds in a very short time -- something on the order of 400 gigabits per second by 1995 and over 13 terabits by 2000. It is extremely unlikely that either the electronics or the demand would support such bit rates.

Pessimistically, a glut of capacity or unforeseen problems in the development of new materials will stall bit rates around the 1.6 or 1.7 gigabit range for the indefinite future.

Most realistically, transmission speeds will continue to increase, but at a slower rate than experienced thus far. Our traffic and cost models (Sections 5.0 and 6.0) are based upon the projection of bit rates increasing to:

- 405 Mbps/565 Mbps in 1985
- 810 Mbps/1.7 Gbps by 1990
- 1.7 Gbps/4.05 Gbps by 1995
- 4.05 Gbps/8.1 Gbps by 2000

The two numbers for each year indicate transmission speeds on routes of low and high traffic densities. These forecasts are based upon expected technological developments, installed plant, and growth in the demand for long-distance services.

1.4.2 Longer Transmission Distances.

Along with an increase in bit rate has been a lengthening in the distances between repeaters. Exhibit 1.3 shows the relationship between bit rate, fiber type, wavelength, and repeater spacings. Improvements in technology have allowed greater speeds to be transmitted over longer distances.

EXHIBIT 1.3

REPEATER SPACINGS, BIT RATE, AND TECHNOLOGY TRENDS

REPEATER SPACINGS

km (miles)

100 (62.2)

50 (31.1)

40 (24.9)

30 (18.6)

20 (12.4)

10 (6.2)

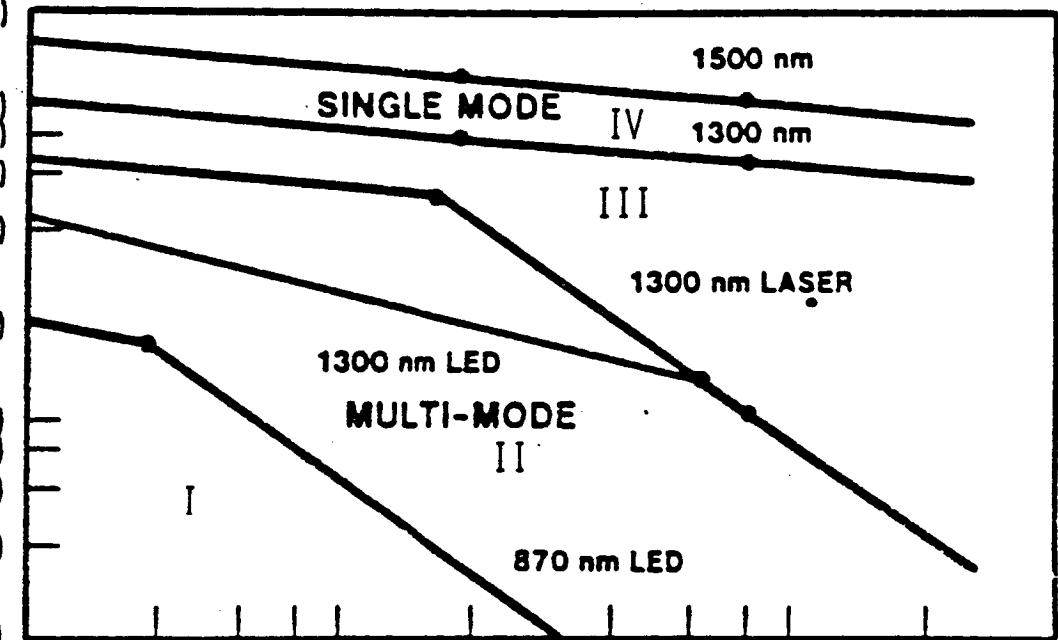
5 (3.1)

4 (2.5)

3 (1.9)

2 (1.2)

1 (.6)



BIT RATE (Mb/s)

Future reductions in attenuation and increases in repeater spacing will depend upon developments on a number of technological fronts. The attenuation level of silica fibers has reached its theoretical limit, making it difficult to squeeze greater distances from current fiber technology (Section 2.2.2). The use of new fiber materials, such as heavy-metal fluorides, could potentially result in repeaterless distances of up to several thousand kilometers. Improvements in lasers are succeeding in narrowing spectral linewidths, thereby increasing power and reducing dispersion, which are major causes of bandwidth limitation (Section 2.4.3.1).

The greatest probable impact on attenuation and transmission distance will be the implementation of coherent detection (Section 2.5.1.2). Analogous to frequency modulation in radio, homodyne or heterodyne coherent communications can result in a 15-20 dB improvement in receiver sensitivity. This could boost repeater spacings to 300 kilometers with existing technology.

According to an optimistic scenario, the long-distance operating companies would embark on a program of implementing the many new technologies that emerge from the laboratories: distributed feedback lasers, coherent detection, and fluoride fibers. By 2000, repeaterless links will span the United States.

The pessimistic scenario foresees technological stagnation. The long haul carriers will continue to rely on existing technologies and will maintain their existing repeaters at 40- to 50-kilometer intervals.

Most probably, the carriers will implement new technologies on an incremental basis. Lasers with narrower spectral widths and coherent detection will be introduced as the technology matures and they become cost-effective. 1990 will probably see the first commercial use of coherent detection, with steady implementation into the next century. The two numbers presented for each year present the "nominal" (theoretically possible) and the "actual" (most likely given terrain and other factors) repeaterless distances:

- 50/40 kilometers in 1985
- 50/40 and 100/80 kilometers by 1990
- 200/160 kilometers by 1995
- 320/240 kilometers by 2000

1.4.3 Move to Longer Wavelengths.

Starting from components that operated at 0.8 to 0.9 microns, fiber optic telecommunications systems have moved through the second window of 1.3 microns to the third window of 1.55 microns. Longer wavelengths offer lower losses in glass fibers because of lower Rayleigh scattering loss.

Hoping to benefit from the lower attenuations achieved at even longer wavelengths, system designers and engineers are designing components that can transmit between 2 and 10 microns. This has necessitated the development of new materials such as heavy metal (hafnium, zirconium) fluoride glasses for fibers and lead tin tellurium (PbSnTe) light sources. Because of the longer distances that be spanned at longer wavelengths, the development and implementation of these systems has obvious implications for the future of long-haul fiber optic networks.

Exhibit 1.4 outlines various technological characteristics associated with fiber optic systems operating at various wavelengths.

EXHIBIT 1.4
THE TREND TO LONGER WAVELENGTHS

	<u>Wavelengths (microns)</u>			
	<u>0.8-0.9</u>	<u>1.3</u>	<u>1.5</u>	<u>2-10</u>
Source	GaAlAs	InGaAsP	InGaAsP	PbSnTe
Detector	Si	Ge/InGaAsP	InGaAsP	HgCdTe
Loss (dB/km)	3.5	0.5-1.5	0.2-0.5	.001-0.1
Distance (km)				
LED	3.0	20	>30	>100
ILD	10.0	30	200	>1000
Status	Mature	Growing	Emerging	Research

It would be overly optimistic to assume that the super-long wavelength systems will be instituted before 2000. In addition to the overcoming the technological problems impeding commercialization of long-wavelength lasers, it is unlikely that the carriers would abandon the billions of dollars they invested in existing plant. In addition, a continuous span stretching from coast to coast is unrealistic because of the need to drop and insert signals along the way.

Most realistically, work through this century will continue on maximizing the performance of transmission at 1550 nm. This will include use of distributed feedback lasers, coherent communications, and dispersion shifted fiber.

1.5 FACTORS AFFECTING FIBER OPTICS DEVELOPMENT

The development of fiber optics technology is subject to constraints from several sources. One of them, of course, is the ingenuity and resourcefulness of the scientists involved. Based on experience, however, this does not seem to pose a serious problem. Given the opportunity, scientific activities are bounded only by the imaginations of the researchers and the laws of the universe.

A critical factor in stimulating fiber optics research and application has been the political, economic, and social environment. An account of this environment is presented in Section 3.2. It should be noted here, however, that the divestiture of AT&T and the deregulation of the telecommunications industry has spurred intense competition within the industry. The result has been a tremendous expansion in the complexity and diversity of products and services in all segments of telecommunications.

To counter what they perceive as competitive threats to "bypass" their networks, the telephone companies have been installing fiber optics at a rate not justified by economic return alone. A further stimulus to fiber optics is provided by wideband services such as videotext, video-conferencing, digital facsimile, electronic mail, and bulk data transmission. The movement toward an Integrated Services Digital Network (ISDN) has also served to whip up enthusiasm for optical transmission.

In short, technical progress in fiber optics has fortuitously coincided with a particular set of economic and regulatory trends that favor its further development. The surge of activity in long distance fiber optic networks must therefore be viewed not solely as recognition of a superior technology, but as part of a broader environment.

SECTION 2.0
FIBER OPTIC COMPONENTS FOR LONG HAUL SYSTEMS

2.1 INTRODUCTION

The evolution of fiber optics systems will depend upon the development of the individual components that make up the system. In this section, we discuss the parts that contribute to the functioning of the whole. Before starting, however, two introductory points need to be made.

First, while there are many components required in a functioning fiber optics system, this section will focus on those components whose performance or cost characteristics significantly affect the future development of domestic fiber optic long distance networks. These components include:

- Optical fibers;
- Cables;
- Splicers;
- Light sources;
- Detectors;
- Multiplexers; and
- Switches.

Other components, such as couplers and connectors are obviously necessary elements in a fiber optic system but have been excluded because they do not constitute a critical variable in the evolution of long haul networks. Because of the limited use of couplers, for example, a decrease in their cost will not affect the planning of network designers. Similarly, a decrease in the loss budget of a connector will not lengthen the distances spanned between repeaters. Comparable arguments could be made for the other components excluded from our analysis.

2.2 OPTICAL FIBERS

An optical fiber consists of two concentric layers. The core, or inner layer, has a refractive index higher than the outer layer, or cladding. Light injected into the core and striking the core-to-cladding interface at greater than the "critical angle" is reflected back into the core by the phenomenon of total internal reflection. Since the angles of incidence and reflection are equal, light striking the interface at more than the critical angle is refracted out of the cladding and is absorbed, or is transmitted out of the fiber.

Total internal reflection therefore forms the basis for light propagation in optical fiber. However, light does not travel randomly through a fiber; it is channeled into various modes, which represent allowed solutions to electromagnetic field

equations. A mode, therefore, is a possible path for a light ray traveling down a fiber.

2.2.1 Types of Fibers

The number of modes that propagate in a fiber is an important criterion in the classification of fiber types. As shown in Exhibit 2.1, there are three basic types of fibers: multimode step index fiber, multimode graded index fiber, and single mode step index fiber.

In multimode step index fibers, the relatively large core diameter (typically 50 to 1000 microns) allows for the propagation of a large number of light modes. Because the modes travel over different path lengths at different velocities, reflecting at different angles from the interface of the core and cladding, they arrive at the receiver at different times. The resulting pulse spread ("modal dispersion") limits the bandwidth of the system, especially at longer distances.

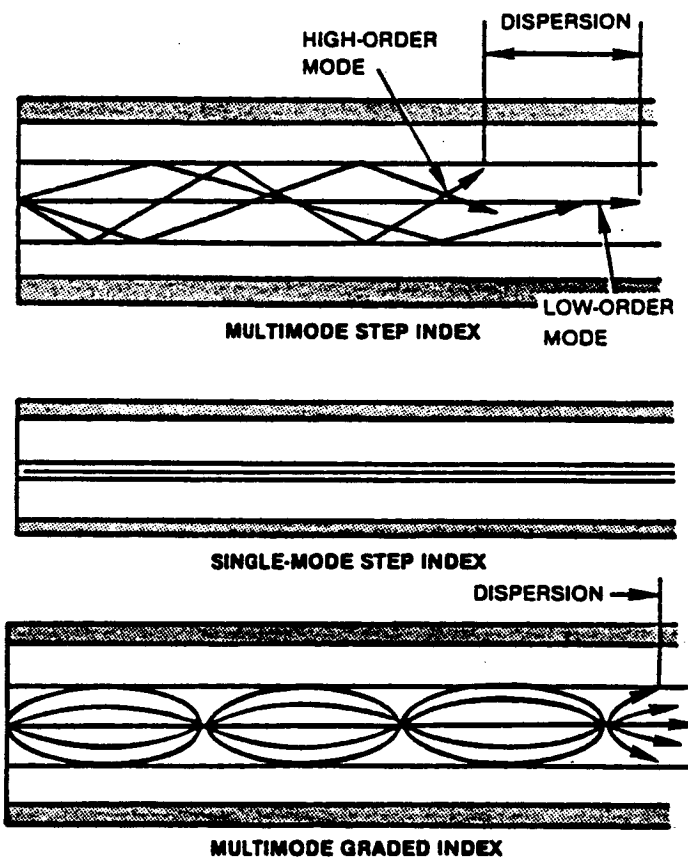
A multimode graded index fiber is designed to overcome modal dispersion. Its core consists of a series of concentric rings, each with a gradually lower refractive index as they extend out from the axis. Since light travels faster in a lower-index medium, light farther from the fiber axis travels faster. The changes of path length and velocity caused by the varying refractive index reduce the differences in propagation time between the various modes reaching the detector. This in turn reduces dispersion of the signal and allows for greater bandwidth.

In single mode step index fiber (also called monomode fiber), the small core diameter (typically 2 to 10 microns) allows the propagation of only one wave mode. This mode travels approximately parallel to the core axis, minimizing dispersion and greatly increasing bandwidth. Operated at longer wavelengths than the other fiber types (above 1300 nm), its use reduces attenuation losses and allows for transmission over longer distances.

Although the first fibers produced were single-mode, difficulties in splicing and connectorization led system designers to work initially with larger-core multimode fibers. Had representatives from the fiber optics industry been polled in 1982, general consensus would have been that multimode fiber would continue to be the predominant type of fiber for the next five years.

EXHIBIT 2.1

HOW LIGHT RAYS TRAVEL IN THREE FIBER TYPES



Source: Amp, Inc.

In January 1983, however, MCI announced its order for 60,000 fiber-kilometers from Siecor and 90,000 fiber-kilometers from Northern Telecom. All of the fiber was to be singlemode. Since then, led by the long-distance industry, the majority of telecommunications applications has shifted completely to single mode fiber. The earlier problems presented by splicing and connectorization have been solved. Given the superior bandwidth and attenuation characteristics single mode fiber, we expect that it will remain the industry standard for the indefinite future.

2.2.2 Fiber Materials

The vast majority of fibers currently being installed in fiber optic systems are made of silica glass. Although press reports about fibers often refer to their "ultra-pure" qualities, the fibers, during the manufacturing process are in fact doped with materials (such as germanium tetrachloride) to alter their refractive indices. Similar processes are used in the manufacture of semiconductors.

With the attenuation levels of silica glass fibers having reached their theoretical limit, researchers are looking to improve production methods that will reduce costs and increase yields. Other activities, being conducted in both the laboratory and the courts, are focusing on finding ways to overcome the limitations imposed by Corning's grip on fiber production patents. A third series of efforts -- to be discussed in more detail in a later section -- are concerned with finding alternative materials for silica. Although research is still in a very formative stage, promising candidates include fibers made from fluoride, chalcogenide, and chloride crystalline materials.

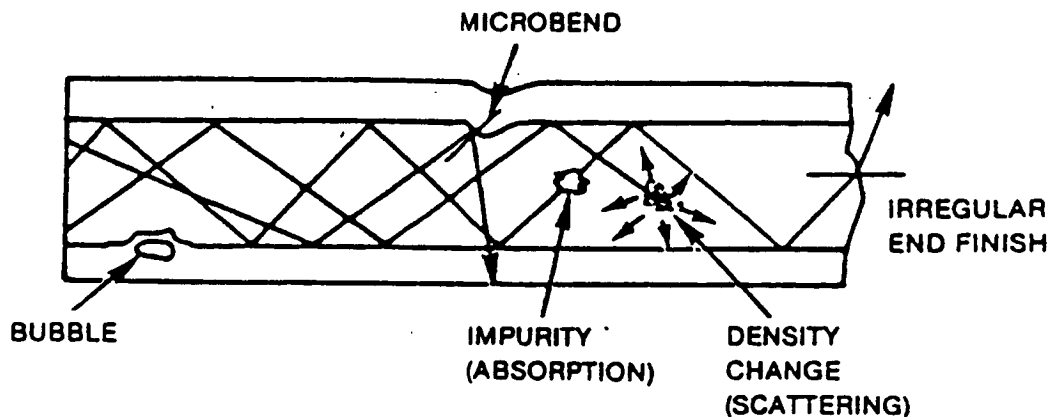
Although of little relevance to long haul systems, mention should also be made of developments in plastic fibers. Operating between 0.5 and 0.7 microns, plastic fibers offer the advantages of low weight, large diameter core, easy connectorization, low cost, and operation in the visible range. As can be expected from the short wavelengths at which they operate and their relatively high loss, these fibers are being used primarily in short-distance applications.

2.2.3 Attenuation

Attenuation of fibers, specified in decibels (dB) per kilometer, is loss of power. During transit, light pulses lose some of their photons, thus reducing their amplitude. For commercially available fibers, attenuation ranges from around 0.2 dB/km for premium small-core glass fibers to over 2000 dB/km for large-core plastic fibers.

Attenuation arises from two causes: absorption and scattering (Exhibit 2.2).

EXHIBIT 2.2
CAUSES OF ATTENUATION



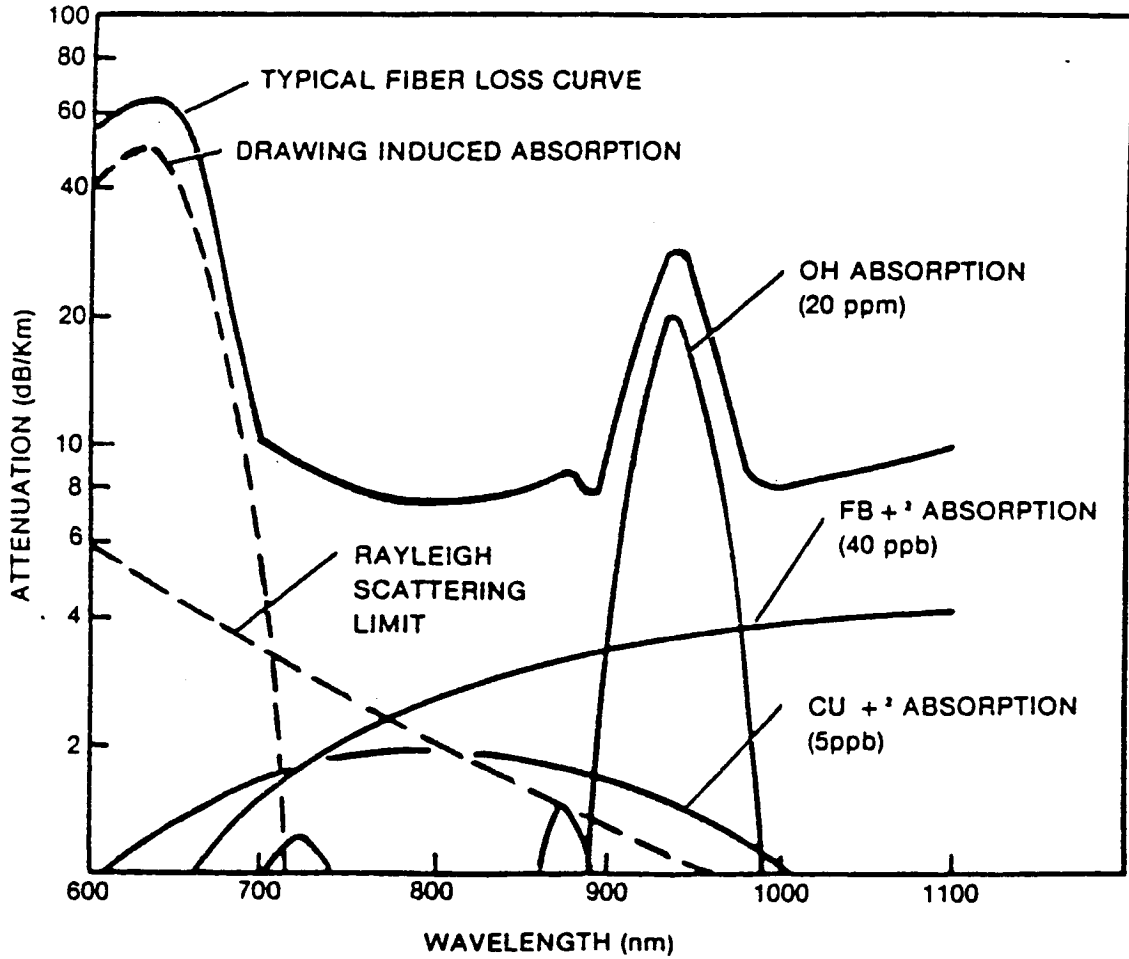
In absorption, impurities in glass, such as water and transition metals, absorb light energy at wavelengths of interest. Some impurities remain as residues in glass after purification and processing; others are dopants added purposely to obtain certain optical properties.

Scattering results from imperfections in a fiber and from the basic structure of the fiber. Unintentional variations in density and fiber geometry occur during fiber manufacture and cabling. Small variations in the core diameter, microbends, and small incongruities in the core-to-cladding interface cause loss. The angle of incidence of rays striking such variations at the core-to-cladding interface mean that some rays are refracted onto new paths not subject to total internal reflection.

An important form of scattering -- Rayleigh scattering -- comes from the atomic and molecular structure of the glass itself and from the density and composition variations that are natural by-products of manufacturing. Rayleigh scattering, which is inversely proportional to the fourth power of wavelength represents the theoretical limits for attenuation. It provides about 2.2-dB/km loss at 820 nm and well under 1 dB/km in the long wavelengths over 1000 nm.

As shown in Exhibit 2.3, the causes of fiber attenuation are strongly associated with wavelength. This results in a number of "windows" within which attenuation is lowest. For telecommunications, these windows are 800 to 900 nanometers, 1300 nm, and 1550 nm (Exhibit 2.4). For good fiber performance, high-absorption regions, such as 950 nm, should be avoided.

EXHIBIT 2.3
RELATIONSHIP BETWEEN WAVELENGTH AND ABSORPTION



(Source: Amp, Inc.)

EXHIBIT 2.4

SPECTRAL TRANSMISSION LOSS FOR TYPICAL SINGLE MODE FIBER

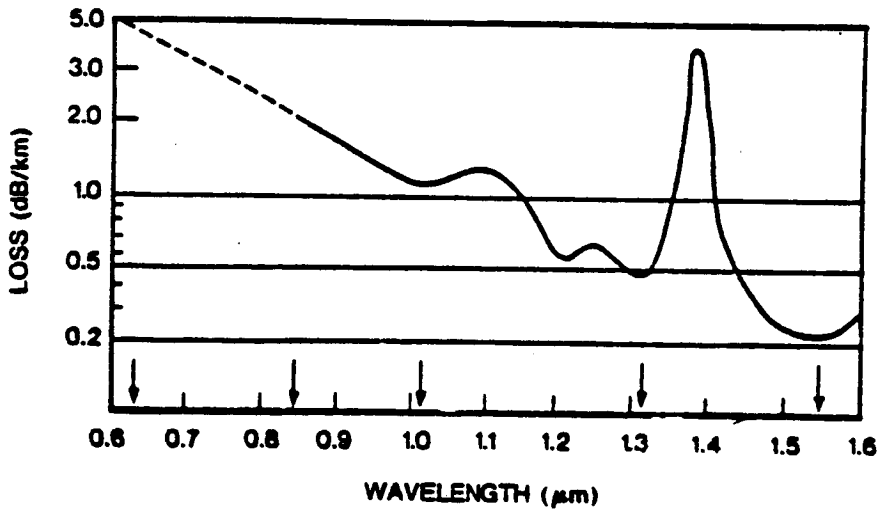


Exhibit 2.5 shows the representative characteristics of a variety of fibers operating at different wavelengths.

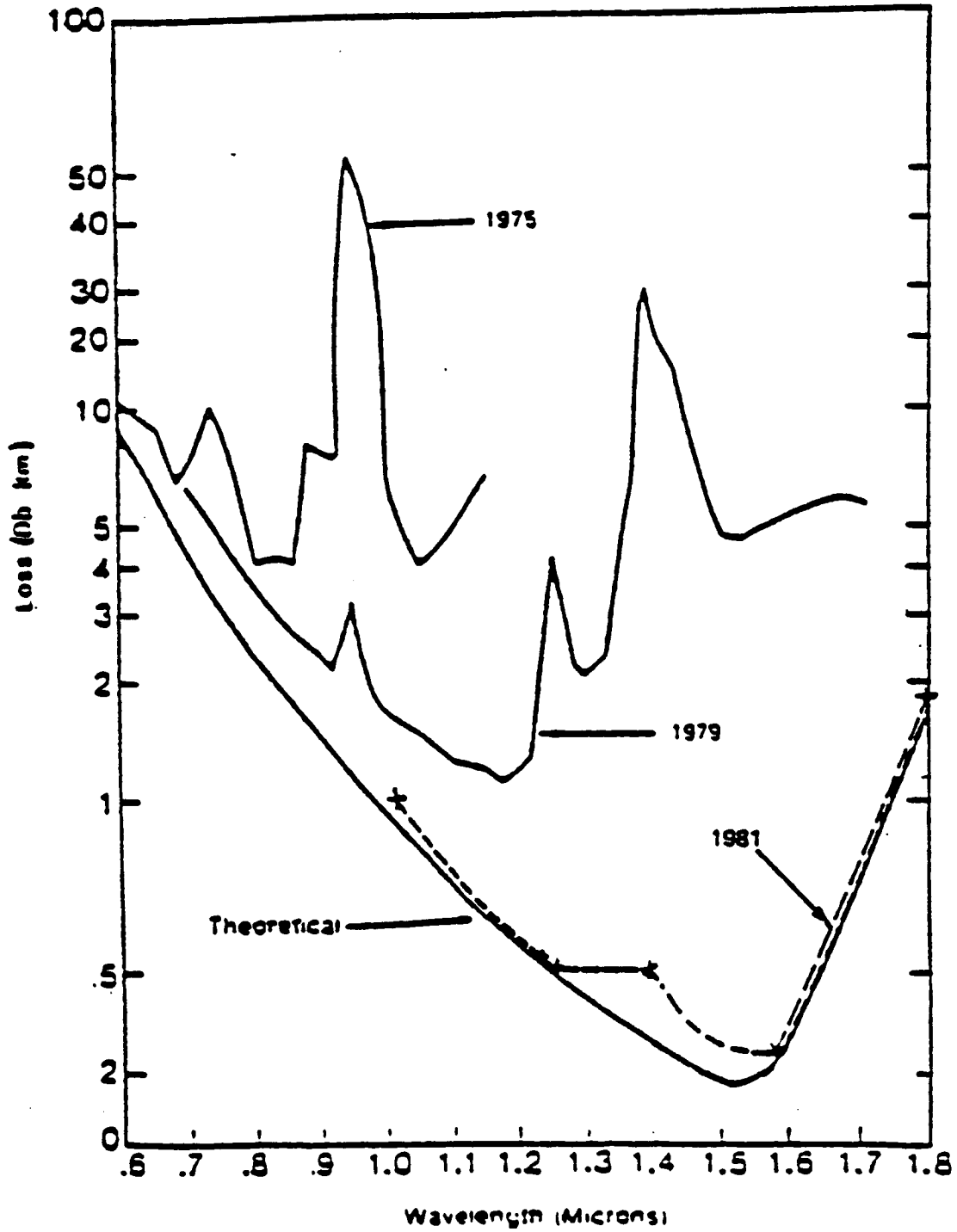
EXHIBIT 2.5
CHARACTERISTICS OF FIBERS

<u>Fiber Type</u>	<u>Core Diam. (microns)</u>	<u>Wavelength (nm)</u>	<u>3dB Bandwidth-Length (MHz x km)</u>	<u>Loss (dB/km)</u>
<u>Multimode</u>				
Plastic	1000	580	---	400
Glass				
Step Index	50	850	23	3
Graded Index	50	850	500	3
Graded Index	50	1300	1000	.1
<u>Single Mode</u>				
Glass	5	850	10,000	2.5
Glass	10	1300	>100,000	0.4
Glass	10	1550	>100,000	0.2

As is evident from Exhibit 2.5, glass fibers have moderately low losses (3-5 dB/km) in the 800-900 nm "first window" range, lower losses near 1300 nm (0.6 dB/km), and lowest losses of all at the 1550 nm "third window" (0.2 dB/km). The 1300-1550 nm range is the "long wavelength" region for optical communications, and is the range at which long haul systems operate.

Much of the progress in optical communications has entailed a decrease in the attenuation of fibers. As shown in Exhibit 2.6, the loss levels of silica fibers had essentially reached their lowest possible levels by 1981. Operating at 1300 nm, single mode fibers made by the Outside Vapor Deposition (OVP) process achieve typical losses of 0.40 dB/km; champion results have attained a 0.27 dB/km loss. When the operational wavelength is shifted to 1550 nm, the typical and champion results are 0.25 and 0.14 dB/km, respectively. In April 1986, Sumitomo Electric produced a fiber with an attenuation value of 0.154 dB/km by removing germanium from the core and adding fluorine to the cladding. In tests using this fiber at 1550 nm, unrepeated transmission distances of 120 kilometers were achieved.

EXHIBIT 2.6
PROGRESS IN GLASS FIBER ATTENUATION



(Source: IGI Consulting)

Fiber material, wavelength, index profile -- all of these factors influence the performance characteristics of a fiber. An important column in Exhibit 2.5 is the fourth, which shows the fiber's bandwidth-length, as measured in megahertz-kilometer (MHz-km), the standard measurement of information-carrying capacity. It will be noted that along with lower attenuation levels, single mode fibers also present the greatest potential for the transmission of high bit rates.

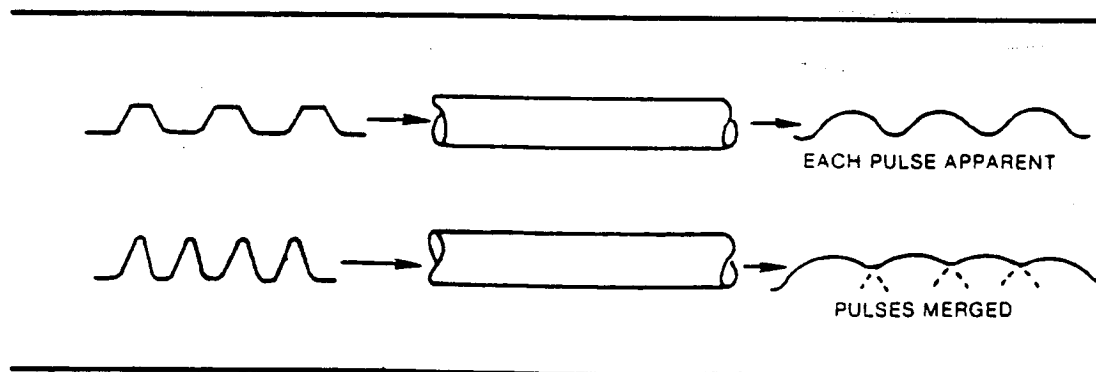
2.2.4 Dispersion Factors Limiting Bandwidth

The bandwidth, or information-carrying capacity, of an optical fiber is limited by three forms of dispersion: modal material, and wavelength. The first is present only in multimode fibers, while the other two depend on the linewidth of the wavelength spectrum being emitted by the light source.

The first of these, modal dispersion, has already been discussed: this is where the different velocities of the various modes in a multimode fiber cause pulses to spread as they propagate. Beyond a certain point, as shown in Exhibit 2.7, the pulses start to overlap, making it difficult, if not impossible, for the detector to distinguish between the incoming pulses. Although single mode fibers' smaller core diameters may make for more difficult handling, their support of only a single mode eliminates the problem of pulse spreading.

Material and waveguide dispersion are both wavelength-dependent. They arise because the way light propagates through materials is a function of wavelength. Both of them are measured in picoseconds (of pulse spreading) per nanometer (of source spectral width) per kilometer. This measurement reflects both the increase in dispersion with wider spectral linewidths of the source and the accumulation of dispersion over distance.

EXHIBIT 2.7 EFFECTS OF DISPERSION ON SIGNAL



(Source: Amp, Inc)

Material dispersion is caused by the variation in refractive index of glass with wavelength. Even when different wavelengths follow the same path, pulses spread because the speed of light in the fiber equals the speed of light in a vacuum scaled by the index of refraction at a given wavelength.

Waveguide dispersion refers to wavelength dependent velocities associated with the structure of the fiber waveguide. In single mode fiber, light is not confined to the core; about 20 percent travels in the cladding. Since the refractive index is lower in the cladding, the tendency is for that light to travel somewhat faster. But because the core and cladding light belong to the same mode and must therefore travel together, it does so at an effective velocity between that of the core and cladding materials. The exact velocity varies with wavelength, so the linewidth of a pulse is an important factor in the amount of waveguide dispersion experienced.

These various forms of dispersion, as indicated earlier, can limit a fiber's bandwidth. Among the efforts being taken to overcome the undesirable effects from this dispersion are the use of single mode fibers, the development of dispersion shifted and dispersion flattened fibers, and the narrowing of spectral linewidths emitted by light sources.

2.2.5 Research and Development Foci

Although the past two decades have seen enormous progress in the development of optical fibers, several constraints have operated to limit the optimal performance of optical systems. Attenuation levels of silica fiber, for example, have reached their lowest theoretical limit. This fact, coupled with the desire by system designers to move to longer wavelengths, has necessitated the development of new fiber materials and types. In addition, even though fiber prices have been steadily falling, the competitiveness of fiber for certain applications depends on further cost reductions.

Research and development is therefore occurring on a number of fronts. The most important of these with relevance to long distance networks are:

- New fiber materials;
- More efficient fiber production processes; and
- Dispersion shifted and dispersion flattened fibers.

2.2.5.1 New Fiber Materials

With the attenuation levels of silica glass fibers having reached their lowest theoretical limits, researchers are developing new fiber materials that can transmit at longer

wavelengths (1.6 to 10 microns) in the far infrared. Prime candidates are presently a class of fibers made of heavy-metal fluorides, especially zirconium fluoride (ZrF_4).

The use of zirconium fluoride glass fibers will allow for transmission at wavelengths of 2500 nm and above. Given the properties of the materials and performance at longer wavelengths, it is anticipated that repeaterless distances of up to 8000 kilometers can be achieved.

Although still in preliminary stages, laboratory results of ZrF_4 fibers are encouraging:

- At the O-E/LASE conference in January 1986, researchers from the Naval Research Laboratory reported the development of an infrared fiber with a loss of 3 dB/km at 2500 nm. At OFC'86 in February, the reported loss was 0.9 dB/km. The fiber uses material called ZBLAN, which is composed of ZrF_4 , BaF_2 , LaF_3 , AlF_3 , and NaF.
- Working with ZrF_4 -based fibers, British Telecom Research Labs concluded that losses of 0.03 dB/km might be expected at 2560 nm.

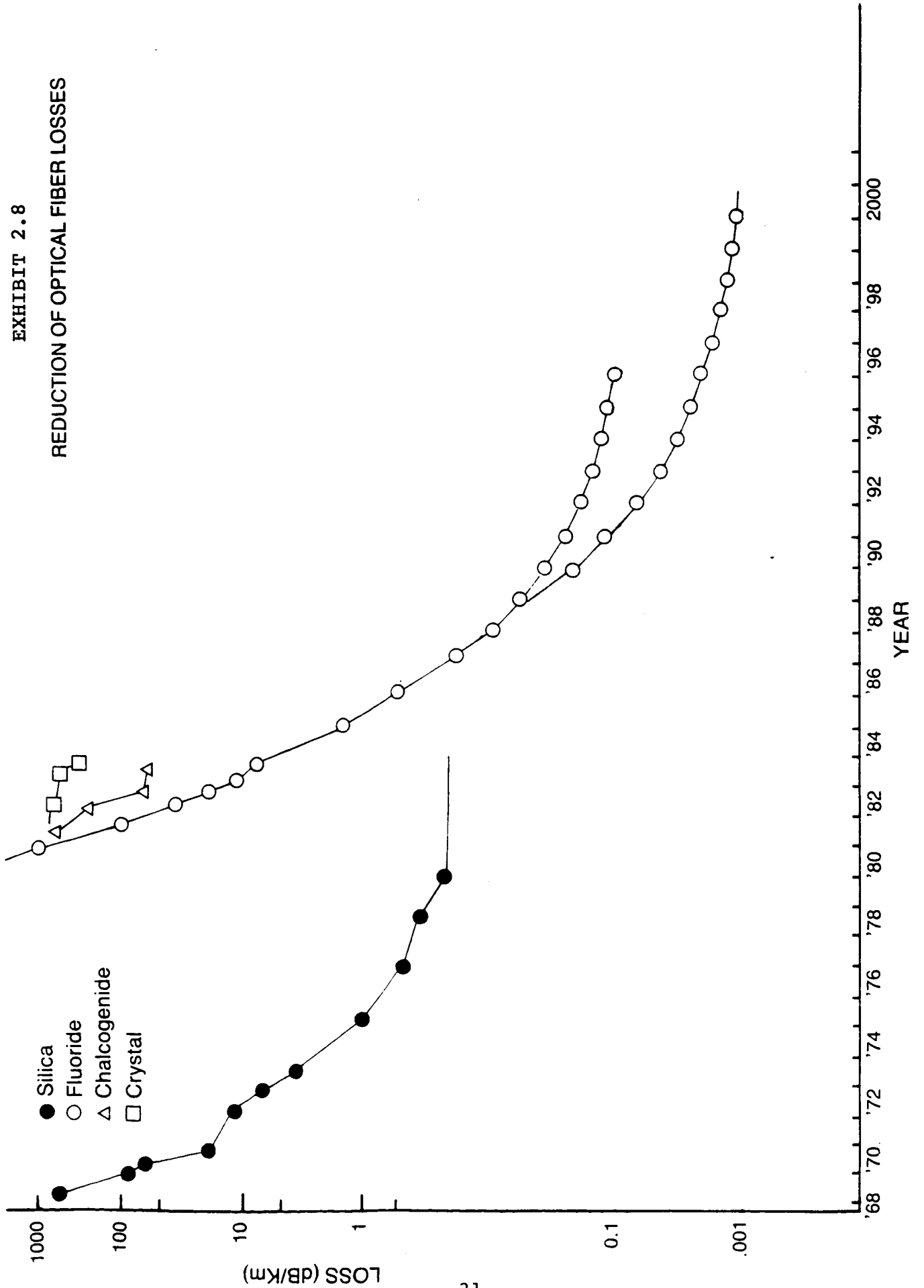
While these results still do not match the low losses currently achieved with silica fibers, it is important to remember that the development of these fibers is still in its infancy. Exhibit 2.8 shows expected attenuation rates for fibers of different materials through the middle of the next decade. Fluoride fiber losses can be expected to drop faster than losses for silica fibers since they will benefit from the learning curve experienced through work with silica.

In addition to long distance communications, fluoride fibers have potential applications in gas analysis, optical temperature sensors, and power delivery systems for medical laser instruments. It is indicative of the seriousness with which these glasses are being viewed by the industry that major manufacturers and the government are investing considerable amounts of R&D funds in their development. The military is interested in long wavelength fibers for long distance undersea sensor systems, in part because they exhibit better radiation resistance properties than silica fibers.

Corning Glass, for example, is experimenting with ways to use its chemical vapor deposition (CVD) process in the production of aluminum fluoride (AlF_3) and beryllium fluoride (BeF_2) fibers. British Telecom is developing a facility at Ipswich for the production of fluoride fibers, presumably for undersea applications. Two firms are now offering long wavelength fibers commercially -- Spectran in the United States, and Le Verre Fluore in France.

EXHIBIT 2.8

REDUCTION OF OPTICAL FIBER LOSSES



The Japanese are moving strongly on the development of fluoride fibers. Furukawa Electric Company is producing a total of 500 kilometers a month of germania glass (GeO_2), zirconium fluoride, and KRS-5 glasses that incorporate thallium bromide and thallium iodide. Kokusai Denshin Denwa (KDD) has used the double crucible method of fiber production, previously used only for silica glass, to produce single mode fiber of ZrF_4 , BaF_2 , NaF , LaF_3 and AlF_3 . Other firms developing infrared fibers are Sumitomo Electric, Horiba Manufacturing, Matsushita Electric, Asahi Glass, and Machida Pharmaceuticals.

2.2.5.2 Production Processes

With the quality of silica fibers reaching very high levels, work is being conducted on increasing the production efficiencies, i.e. deposition rates, drawing speeds and yields. It is expected by manufacturers that increased production will ultimately result in continued lowering of costs.

NTT, for example, announced a multi-flame vapor axial deposition (VAD) process that it claims lowers that cost of production of fibers to one-tenth that of the conventional VAD process.

Manufacturers are also interested in developing new methods of fiber production because of Corning's current stranglehold on basic fiber production and process patents. At present, most manufacturers operate under Corning licensing agreements. A variety of suits have been filed over the past few years, but they have not provided definitive judgment on the validity of the Corning patents. Litigation is, of course, a complex issue and cannot be fully explored here. Suffice it say that the search for new methods of fiber production is motivated by more than just technical considerations. However, no new processes are expected to be developed over the next decade that can compete economically with the vapor deposition method.

2.2.5.3 Dispersion-Shifted and Dispersion-Flattened Fibers

As indicated earlier, dispersion constitutes a significant constraint on a fiber's bandwidth capacities. However, since material and waveguide dispersion add algebraically and they often have different signs, fibers can be structured such that the two cancel each other out. For a simple step-index fiber this cancellation occurs near 1300 nm. Within the past year, special fibers -- called "dispersion-shifted fibers" (DSF) and "dispersion-flattened fibers" -- have emerged. Dispersion-shifted fibers shift the point of minimum dispersion from 1300 nm to 1550 nm, a wavelength at which longer transmission distances can be achieved whereas dispersion-flattened fibers offer a very low dispersion over a broad wavelength range of 1300 to 1550 nm. Because of its operation at 1550 nm, dispersion-shifted fibers

currently offer higher data rate and transmission over longer distances. Dispersion-flattened fiber, because of its ability to transmit in both the 1300 and 1550 nm windows, is better suited for wavelength multiplexing.

Pioneered by Corning, these fibers have attracted a good deal of attention and experimentation at a number of laboratories. Among them are:

- Corning Glass and Plessey transmitted at 565 Mbps over 80 unrepeated kilometers, with attenuation of 0.22 dB/km.
- British Telecom, in two trials, reported 140 Mbps over 220 kilometers, and 34 Mbps over 233 kilometers.
- Plessey, in an experimental trial, reported 1.3 gigabits over a 107-kilometer link.

Corning has invested high levels of investment in the success of its dispersion-shifted fiber. As their patents expire for the current generation of optical fibers, Corning would like to have a head start in the development of the next generation of fibers. In addition to years of R&D, Corning has committed 20 percent of the capacity of a new \$87-million plant in North Carolina to DSF.

It remains to be seen if dispersion-shifted fibers can capture the hearts and pocketbooks of fiber users. Corning has been promising dispersion-shifted whereas many system designers favor the characteristics of dispersion-flattened fibers. Development of dispersion-flattened fibers is not as advanced because the task is more complex because of the 1300-1550 nm range over which low dispersion is maintained.

At present, the price for DSF is 50 percent higher than for conventional single mode fiber, and dispersion-flattened fiber is not yet commercially available in quantity. Full-scale production at existing facilities was only attained at the end of 1985, however, and given industry precedents, it is very likely that even greater production levels could make the price of DSF more competitive with other fibers. Another potential constraints on the acceptance of DSF is the low availability of sources and detectors that operate at 1550 nanometers.

One regional fiber optic network, LDX NET, has already incorporated dispersion-shifted fibers in part of its system. Using a hybrid cable developed by Ericsson, twelve single mode and twelve DSF fibers were installed in LDX NET's Kansas City to Joplin, Missouri link.

2.2.6 Optical Fiber Prices

Along with an increase in the performance characteristics of fibers has come a steady decline in the price of optical fiber. In 1980, the price of single mode fiber was, on average, \$2.62 per fiber meter. Five years later, due to increased production volumes and better production methods, the price had fallen to a little over 32 cents per fiber meter.

Indications are that this trend will continue. Exhibit 2.9 shows trends of actual prices of single mode fibers, as well as forecasts of optimistic, pessimistic, and probable prices.

2.2.7 Suppliers

Although a number of manufacturers produce optical fiber, the U.S. market is dominated by five major producers (Exhibit 2.10).

2.2.8 Forecasts

The characteristics and performance of optical fibers constitute one of the most critical set of variables determining the future of optical transmission.

2.2.8.1 Bandwidth

Progress is continuing to be made in increasing the bandwidth-length, the most common measurement of fiber performance. As shown in Exhibit 2.11, it is expected to increase by a factor of 10 between 1985 and 1995.

EXHIBIT 2.9

PRICE TRENDS OF CABLED SINGLE-MODE FIBER
 (\$/meter)

	<u>Optimistic</u>	<u>Probable</u>	<u>Pessimistic</u>
1980		2.62	
1982		.96	
1983		.50	
1984		.40	
1985		.32	
1986	.20	.26	.40
1987	.18	.23	.38
1988	.17	.19	.36
1989	.16	.18	.34
1990	.15	.17	.32
1991	.14	.16	.30
1992	.13	.15	.29
1993	.12	.14	.28
1994	.11	.13	.27
1995	.10	.12	.26

(Source: IGI Consulting 1986)

EXHIBIT 2.10

1985 U.S. FIBER PRODUCTION

<u>Company</u>	<u>Fiber Production (fiber-km)</u>
AT&T Technologies	800,000
Corning Glass	450,000
ITT/EOPD	125,000
SpecTran	30,000
Northern Telecom	30,000
Others	<u>30,000</u>
TOTAL	1,465,000

(Source: Kessler Marketing Intelligence)

EXHIBIT 2.11

SINGLE-MODE FIBER PERFORMANCE
BANDWIDTH (GHz/km)

	<u>Optimistic</u>	<u>Probable</u>	<u>Pessimistic</u>
1985	200	100	50
1990	1000	500	100
1995	2000	1000	500

(Source: IGI Consulting 1986)

The optimistic projection is based on significant progress in high-speed systems, which in turn depends upon the development of new materials and single-frequency lasers. Bandwidth may be further increased significantly through the use of coherent transmission and wavelength division multiplexing. In addition, achievement of this greater bandwidth will require sufficient market demand to warrant the development of these faster systems.

2.2.8.2 New Fiber Materials

Despite the enormous potential of fluoride fibers, it is unlikely that they will be widely deployed in domestic networks by the end of the century. Given both the tremendous investment being made in silica fiber cables and the capacity of those cables to meet future demand, few if any companies will embark on a program of replacement. Fluoride fibers may be used to supplement existing cables, but we anticipate that this will occur on limited routes. The major application of these fibers will be in undersea routes and specialized applications, an area outside our scope of investigation.

2.3 CABLES

For most applications, optical fiber must be cabled by enclosing a fiber or fibers within a protective jacket. The cable must protect the fiber throughout its lifetime, especially during installation when greater stress is likely to be applied to the fiber.

Two main construction methods are used to encapsulate a fiber in a cable: the tight jacket or the loose tube. The tight jacket uses a material such as PVC or polyurethane applied tightly around the fiber and offers the advantages of bend radii and better crush resistance. These attributes make tightly jacketed fibers ideal for short-distance applications in places like a computer room where sharp bends may be encountered or the cable will likely be placed under a carpet and be walked on.

In loose tube fiber cables, the fiber is placed within a plastic tube that has an inside diameter several times larger than the fiber's diameter. Such loose-tube encapsulation isolates the fiber from the rest of the cable, allowing for the cable to be twisted, pulled and otherwise stressed with little effect on the fiber.

Long distance networks typically contain loose tube fibers since the decoupling of the fiber from the tube allows the cable to be pulled during installation without harming the fiber. Long haul fiber cables are also constructed with steel sheathing for protection from rodents and the elements. Cable strength members are typically made of Kelvar aramid yarn or steel either in the center or at the periphery of the cable. If moisture is an anticipated problem, the tubes may be filled with jelly, powder, or pressurized air. A problem did arise with regard to hydrogen production in cable materials and subsequent absorption by the fibers, resulting in increased loss. This problem has since been solved by the more judicious use of cabling materials.

2.3.1 R&D Foci

Cable design and construction present few obstacles to the continued rapid deployment of optical systems. Greater tolerance for cold temperatures, more gopher-proof materials, higher tensile and compressive strength, increased resistance to water penetration -- these are areas in which progress is continuing to be made. But while these activities will enhance system reliability and minimize disruptions, they will not affect the rate at which fiber optic long haul networks are deployed.

Two issues, however, are important to the future development and capabilities of long haul networks -- cable lengths and fiber density.

2.3.1.1 Longer Cable Lengths

As fiber manufacturing processes improve, longer glass preforms can be fabricated and pulled to longer fiber lengths. Improved cable manufacturing techniques and materials are able to protect these lengthy fibers from stress and environmental factors. Siecor, for example, introduced 12 kilometers of continuous cable length on reels of 96" diameter or less. AT&T has announced the availability of 14-kilometer cables.

For long distance fiber optic system operators, this has especially significant effects on both construction time and costs. Because more ground is covered with a cable span, system planners can exhibit greater flexibility in their system design and installation methods. Transportation and storage costs are decreased because fewer reels have to be transported and stored at the construction sites. The number of splice points are reduced, saving valuable installation time and effort. AT&T estimates that with its 14-kilometer cable, the expense of splicing operations can be reduced by 75 percent.

To facilitate use of these longer lengths, Siecor has designed them to be easily used with currently available installation equipment and is producing both unarmored and armored cable in the twelve kilometer lengths. As new materials, new manufacturing techniques, and new product designs develop, it would not be surprising to see even longer continuous cable lengths appear on the market.

2.3.1.2 Number of Fibers in Cables

The number of fibers placed in cables will depend on the particular application. High-density urban trunks require a larger number of fibers to carry the greater traffic load. In April 1986, Siecor delivered a 156-fiber cable to the Chesapeake and Potomac Telephone Company for use in the Washington, D.C. area. Siecor officials expect to be producing cables with 192 fibers in the future.

Within long haul networks, fiber counts are much lower. Exhibit 2.12 shows the average number of fibers for each of the national and regional long distance networks. In the early installations, higher fiber counts were used because of the uncertainty of the technology and the lower bit rates used. As bits rates increased, and as greater confidence in the fibers developed, fiber count has shown a steady decrease.

It should be noted that the national networks -- AT&T, MCI -- have the highest fiber counts. In our forecast and model, we assume fiber counts of 48 and 96 fibers, depending on the traffic density of the particular routes. Our use of higher fiber counts is justified by the fact that our model network, which is also

national, would presumably carry a great share of the country's communications traffic.

EXHIBIT 2.12
AVERAGE FIBER COUNT FOR SELECTED LONG HAUL NETWORKS

AT&T	24
Electra	22
Illinois Consolidated	11
Lasernet	10
LDX	24
LiTel	24
MCI	44
NTN	15
RCI	24
SoutherNet	10
Southland Fibernet	10
Sprint	18
Wiltel	10

(Source: IGI Consulting 1986)

2.3.2 Splicing

The miniscule diameter of fibers and the need for precise alignment of fiber cores have made cable splicing an extremely important issue in the implementation of optical networks. The transition to single mode fiber, with its even smaller core, made the development of efficient splicing techniques even more critical. Conventional splicing methods had been time-consuming. Even with special alignment tools, one splice could take as long as one-half hour. These problems have largely been overcome.

There are two main methods of splicing fibers, both of which are used to form a junction between fiber ends so that loss of

optical power is minimal. Fusion splices, the first of the two to be developed, "weld" the fiber ends together with an electric arc. Mechanical or bonded splices involve aligning the two fiber ends and then permanently setting them with a bonding agent. Mechanical splicing techniques were developed by GTE (elastomeric splice) and AT&T and TRW (bonded splice). On the whole, mechanical splices are less costly and labor-intensive. In the case of AT&T, fiber ribbon mechanical splices can be prepared in the factory rather than in the field.

The loss budget of splices is an important consideration, especially in long-distance networks. Loss levels can climb as high as 0.5 dB, although both proponents of both methods claim that regular loss levels are 0.2 dB or better.

A significant advance in the splicing techniques was the development by Bell Laboratories of single-mode ribbon cable, in which 12 fibers are sandwiched between two mylar strips; up to 12 ribbons (144 fibers) can be combined into one cable. For long-distance routes, each of the fibers is aligned and spliced individually, taking on average 10 to 20 minutes.

2.3.3 Cable Prices

The dropping price of fibers also translates into cable price declines. Between 1983, when a meter of cabled single mode fiber cost fifty cents, and 1990, the price for a fiber-meter of cable will be slashed by over fifty percent.

2.3.4 Suppliers

Many of the fiber manufacturers -- AT&T, Corning [Sicor], Northern Telecom, ITT -- are also involved in the supply of optical cable. Exhibit 2.13 shows the estimated dollar values of cable shipments for the major suppliers.

2.3.4 Forecasts

Although improvements will continue to be made in cable design and materials, these will have little effect on the development of long haul networks. Similarly, longer cable lengths may ease construction and lower costs, but they will not alter decisions about network configuration.

EXHIBIT 2.13

ESTIMATED CABLE SHIPMENTS
(millions of dollars)

	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1990</u>
AT&T Technologies	80	120	375	500	1500
Siecor	25	45	120	80	500
Northern Telecom	5	30	60	90	300
Ericsson	5	10	30	45	250
ITT (Valtec)	10	15	25	50	200
Others	<u>10</u>	<u>20</u>	<u>30</u>	<u>60</u>	<u>100</u>
TOTAL	135	240	640	825	2850

2.4 LIGHT SOURCES

Light sources, along with the necessary drive electronics, are used to change electrical signals to optical signals and launch the signal down the fiber.

2.4.1 Requirements for Light Sources

Ideally, light sources used for optical communications have the following characteristics:

- Sufficient power and brightness to stimulate the detector;
- Sufficiently fast response to meet the bandwidth requirements of the system;
- A small emission area, preferably no larger than the fiber core;
- Close access to emitting surface, thereby permitting direct fiber coupling;
- A wavelength compatible with the fiber and detector;
- Low power consumption;
- Long life and high reliability;
- Power stability; and
- Low cost.

There are two semiconductor devices that approach these ideals: the semiconductor laser diode (LD) and the light-emitting diode (LED). Both are typically made of gallium arsenide (GaAs) or related III-V compounds (InGaAsP).

LEDs are produced using normal semiconductor diffusion growth techniques. A p-n junction is made in the material, across which electrons and holes migrate when the diode is forward biased. Recombination of these carriers results in the emission of a photon of optical energy, with a wavelength (typically 500 to 1600 nanometers) approximately equal to the energy gap of the LED material.

In a laser diode, an optical "cavity" is formed by cleaving opposite ends of a chip to create two highly reflective surfaces. At low drive currents, the device operates like an edge-emitting diode, spontaneously emitting light. While most of this emission escapes, a small proportion is reflected between the semi-

transparent mirrors at the front and back of the laser. With a sufficiently high initial energy level, the confined radiation stimulates the release of more photons, emitted with the same wavelength, phase, and direction. While a portion of the light remains trapped, stimulating further emission, the rest escapes through the two cleaved ends as intense beams.

Although lasers and LEDs can operate as light sources for fiber optic systems, there are differences in their performance characteristics.

LEDs provide less power and operate at slower speeds, making them quite suited for most applications requiring transmission distances up to several kilometers and speeds up to several hundred megabits per second. The LED, to its advantage, is more reliable, less expensive, easier to use, and generally has a longer lifetime.

As we will see, however, the laser diode is the source more suited for long-distance and high bit rate fiber optic networks.

2.4.2 Laser Performance Characteristics and Trends

The reasons for the laser's preferred status have to do with several of its performance characteristics, including:

- Bandwidth and bit rate
- Operating wavelength
- Spectral linewidth
- Launching power
- Beam Shape

2.4.2.1 Bandwidth and Bit Rate

A light source must be able to turn on and off fast enough to meet the bandwidth limits of the system. The speed of the source is partially determined by its rise time, which is the time required to go from 10% to 90% of peak power. Lasers typically have rise times of less than 1 nanosecond; the rise times of LEDs range from 3 to 100 nanoseconds.

The faster rise time of lasers gives them their greater bandwidth capabilities. Edge-emitting LEDs have a bandwidth range between 20 and 500 MHz. Lasers, on the other hand, can achieve bandwidths of up to 1500 MHz.

Many of the long haul systems currently operate at 565 Mbps. Fujitsu has recently announced the availability of an 810 Mbps system, and MCI announced in May 1986 the first commercial installation of an 810 Mbps systems.

2.4.2.2 Wavelength

Because of the lower attenuation that can be achieved at longer wavelengths, the trend over the past few years has been toward the "second window" of 1300 nm. It should be noted that LEDs can also operate at this wavelength, and that this is not one of the unique characteristics of lasers.

All of the long-distance networks presently operate in the 1300 nm range, although some system operators are anticipating a migration to 1550 nm when the equipment becomes available.

2.4.2.3 Spectral Width

To eliminate material dispersion, which can severely hamper effective transmission over long distances, a light source should ideally produce a single wavelength. Unfortunately, all sources emit a number of wavelengths around the desired focal wavelength. This measurement, called the spectral width, is usually measured as full width at half of maximum intensity (FWHM).

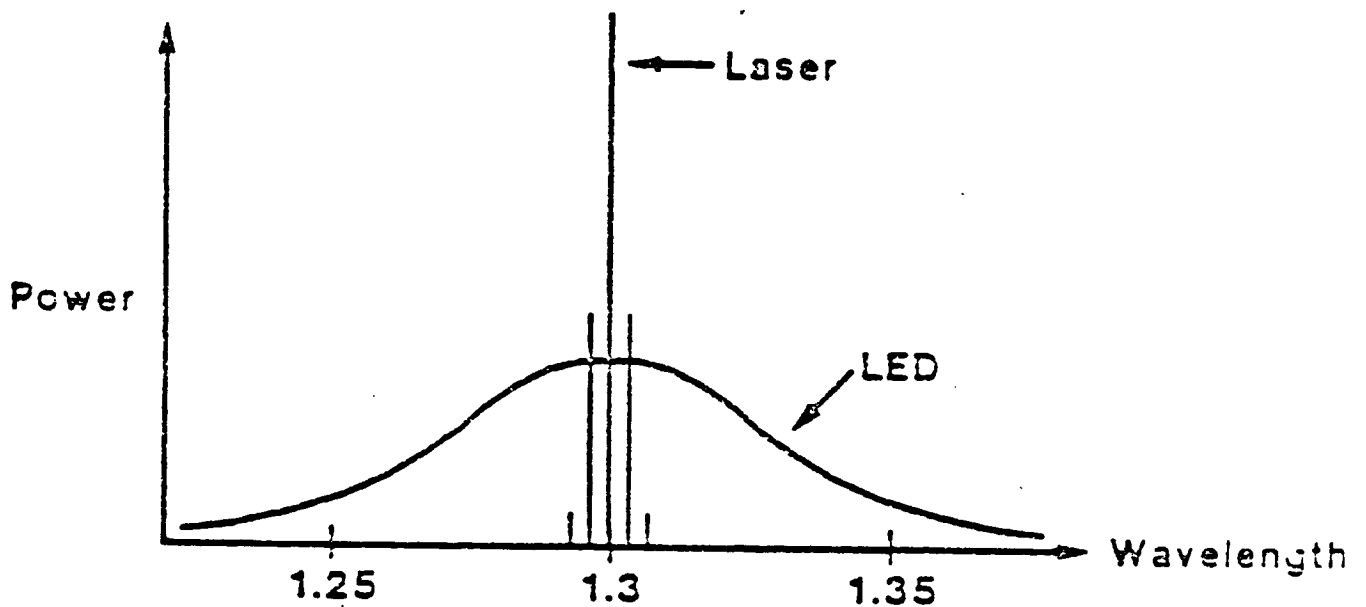
By this criterion, lasers become a much more desirable light source for long-distance transmission. The spectral width of laser emission range from around 1 to 6 nanometers. The spectral width of LEDs is several times wider, typically between 24 and 40 nanometers (Exhibit 2.14).

2.4.2.4 Launching Power

It is desirable to couple as much of a source's power into a fiber as possible. LEDs have outputs in the microwatt range, while lasers have outputs that can exceed 10 mW. A laser, because it is more powerful and has a directional output, typically can couple 1 milliwatt or more power into a fiber than can an LED (Exhibit 2.15). For long distance transmission, this greater output power makes it a more desirable source.

EXHIBIT 2.14
SPECTRAL WIDTHS OF LASERS AND LEDs

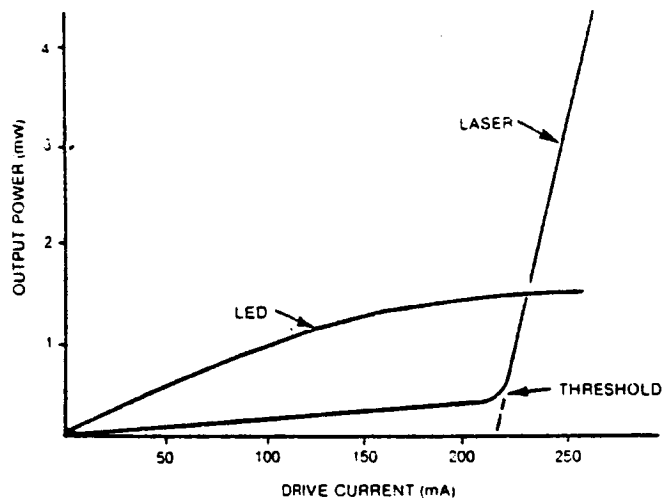
LASERS VS. LED'S



Spectral Width (FWHM):
LED ~ 80nm
Today's Lasers ~ 4nm

(Source: Bell Communications Research)

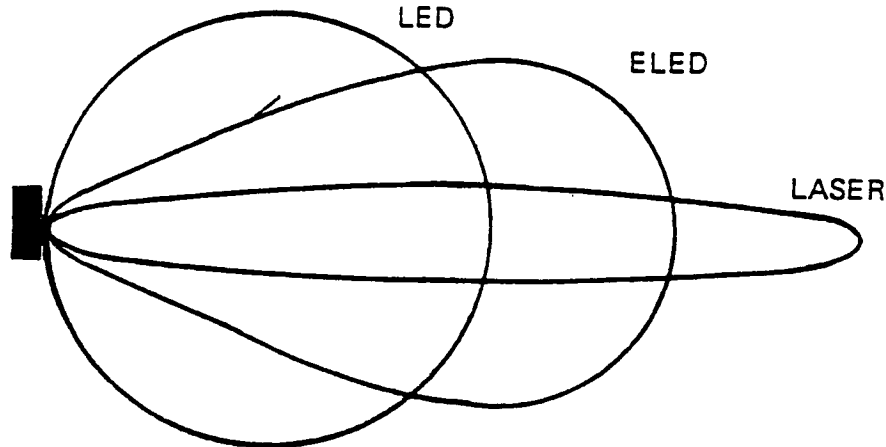
EXHIBIT 2.15
OUTPUT POWER AND DRIVE CURRENT OF SOURCES



2.4.2.5 Beam Shape

One factor affecting the coupling efficiency of a light source is the emission pattern of the beam. Surface-emitting LEDs radiate light in a Lambertian pattern, which allows rays to hit the fiber outside of its acceptance angle. This means that a large amount of the power generated by the surface emitter will be rejected by the fiber. Edge-emitting LEDs (the ELEDs in Exhibit 2.16) concentrate their radiation more than surface devices, thereby providing improved coupling efficiency. Laser diodes radiate within a much smaller angular region. This asymmetric emission provides for more efficient coupling and allows more of the source's light to be concentrated within the fiber.

EXHIBIT 2.16
BEAM SHAPE OF LIGHT SOURCES



2.4.3 Research and Development Foci

Improvement in the performance of long distance fiber optic systems can be achieved through the move to higher bit rates and longer wavelengths. In the area of optical fibers, such improvements are being sought, for example, through the development of dispersion shifted fiber and new fiber materials.

With these same goals in mind, considerable effort is also being made to improve the performance of light sources. This work is proceeding in three major areas:

- Distributed feedback lasers;
- Production processes;
- Improvement in performance characteristics of LEDs;
- Higher output power of laser diodes;
- Reduced Drive Currents.

2.4.3.1 Distributed Feedback Lasers

Although transmission at 1550 nm results in lower attenuation, there is a problem accompanying operation at this wavelength: conventional laser diodes operating at 1550 nm oscillate at multiple wavelengths, i.e. they produce signals with wavelengths slightly higher or lower than 1550 nm. With these signals travelling at different speeds, dispersion, particularly over long distances, can become a significant problem. In other words, despite the relatively narrow spectral bandwidth of lasers, it is still too wide for operation at 1300 and 1550 nm. Reliable transmission at 1550 nm therefore requires the

development of a laser diode that emits light stably at a single frequency wavelength when modulated at high speeds.

Distributed feedback (DFB) lasers offer a solution to this problem. First developed at Bell Laboratories, they contain a corrugated grating with peaks and troughs spaced in such a way that light in only one longitudinal mode is propagated. The function of the grating is to use optical diffraction from its surface to selectively prefer light of a particular wavelength.

Researchers at Kokusai Denshin Denwa (KDD) in Japan had achieved room-temperature oscillation with this type of laser as early as 1981. Subsequent work has focused on improving reliability and fabrication techniques. According to KDD, one of the great advantages of the distributed feedback laser is its relatively simple fabrication, which uses photolithographic processes. For example, of 100 samples produced in one batch, 95 have been without defects. CNET, the R&D arm of the French PTT, has also used the DFB laser.

The linewidth of a few angstrom has effectively reduced the spectral width of the laser by a factor of 250. These lasers are currently being sold commercially in limited quantities in Japan, the U.S., and Europe.

2.4.3.2 Production Processes

Liquid-phase epitaxy (LPE) is the older and less expensive process for producing lasers. Some companies are investing in metallorganic chemical vapor deposition (MOCVD) as a new method of production. Although more expensive than LPE, MOCVD holds out the promise of producing lower-cost devices through an increase in manufacturing yields.

2.4.3.3 Use of LEDs with Single Mode Fiber

As indicated earlier, LEDs offer a number of advantages over lasers: increased reliability, simpler circuitry, greater stability in a range of temperatures, longer lifetimes, and generally lower cost.

Although at one time considered impractical, edge-emitting LEDs are now being considered as a viable light source for single mode fiber. As shown in Exhibit 2.17, research on LEDs and single mode fiber are conducted at a number of laboratories.

Most of the work being conducted on the use of LEDs with single mode fiber is occurring in metropolitan areas, where links are relatively short. However, with a maximum (at present) practical range of 20 to 30 kilometers and future improvements, long-wavelength (i.e. 1300 nm) LEDs may become feasible for certain long-distance applications.

EXHIBIT 2.17
LED/SINGLE MODE FIBER EXPERIMENTS

Laboratory	Mb/s	km	LED	DET
Bellcore	560	25	SL	APD
Bellcore	560	15	EE	APD
NEC	560	5	SE	APD
Bellcore	560	4.5	SE	APD
Bellcore	280	7.5	EE	APD
AT&T	180	.35	EE	APD
Bellcore	140	50	SL	APD
Bellcore	140	35	EE	APD
GTE	140	30	SL	pin
Bellcore	140	22.5	EE	pin
Bellcore	140	15*	EE	pin
AEG	140	12	EE	pin
Bellcore	140	4.5	SE	pin
BTRL	34	11*	EE	pin
CNET	27MHz	12	SE	APD
Plessey	16	107	SL	pin

*Bidirectional transmission

(Source: Paul Shumate, Bellcore)

Researchers at Bell Communications Research are developing high bit rate LEDs for operation over long distances. Through the use of linewidth-narrowing spectral filters, 140 Mbps have been transmitted over 35 kilometers of single mode fiber, and 565 Mbps over 25 kilometers. Results of hero experiments using 1550 nm edge-emitting LEDs should be announced during 1986, and work is proceeding on the development of LEDs that can operate at the 2000 to 3000 nm wavelength range.

2.4.3.4 Higher Power Output of Laser Diodes

As indicated earlier, laser diodes must emit enough power to be detected at the other end. Long distance transmission requires even greater levels of power output. One of the foci of development has therefore been to increase the power levels of lasers, which are currently in the 10 to 20 milliwatt (mW) range, although lasers up to 200 mW are also available. By 1990, lasers will be available and used that have power outputs of up to 100 milliwatts. This output power will make it possible to have coupled power of more than 10 mW in the fiber.

Three techniques are being developed to boost the output of a laser. First, increasing the size of the lasing spot creates a narrower far-field beam and prevents the mirror facets from being degraded at continuous power levels in the 20 to 50 milliwatt range. Second, applying an antireflection coating to the laser's front facet increases the ratio of the diode's emitted power to internal power. The third technique is to devise mirror regions that are not pumped by the drive current and do not absorb the lasing light.

2.4.3.5 Reduced Drive Current

In addition to increasing the output power, researchers are looking to decrease the amount of drive current needed to cause lasing. This is an important consideration because high temperatures associated with high currents lead to laser degradation and wavelength instability. At present, current requirements are around 100 milliamps. Within ten years, however, drive current should be in the 10 to 20 milliamp (ma) range.

2.4.4 Light Source Prices

As with other components, the prices of lasers and LEDs have been falling steadily. An industry update in the May 1986 issue of Lightwave reported that over the past year, the price of lasers has decreased by 50 percent.

From an average \$2200 per laser reported in May of 1985, the price of a conventional 1300 nm packaged device was \$1350 in 1986. Some industry analysts expect the price to drop by late 1986 to \$1000 or \$1100 per laser for large orders (over 1000).

While the prices of conventional lasers are dropping, the price of special lasers is still high. A long-wavelength laser with premium performance and guaranteed lifetimes can still cost up to \$2000. Distributed-feedback lasers now cost as much as \$10,000. As production processes improve, production volumes increase, and demand grows, the cost will come down, although it is difficult to forecast a time frame or slope for that reduction.

It is uncertain how much faster or further laser prices can drop. If, as some people predict, the price is reduced to \$600, the effect on long-distance fiber optic networks will probably be minimal. Lasers constitute a very small portion of network cost, and the price elasticity is very low. The real effect of lower prices will be seen in the local loop, where the short distances and high source density make potential application of fiber optics very sensitive to price.

One very likely effect of lower laser prices is a curb in interest in LEDs as a light source for long-distance networks. Packaged LEDs are currently selling for \$500, and the small differential in price does not compensate for the much greater performance of lasers.

2.4.5 Suppliers

One reason for the drop in prices has been the entry into the market of new suppliers. From the half-dozen companies supplying long-wavelength lasers in 1985, the number of suppliers has tripled.

The largest U.S. manufacturer of lasers is AT&T and Lasertron. Other major suppliers include Fujitsu, Hitachi, Mitsubishi, NEC, General Optronics, ITT, RCA, and Lytel.

In the present market turmoil, some suppliers are reducing their prices in an attempt to buy market share. This constitutes another factor in this year's price reduction.

Despite the uncertain market, some companies are expanding their investment in laser R&D and production.

- British Telecom and Dupont announced in April the investment of \$100 million in a new joint venture to produce lasers, receivers, and other components. Located in England, the facility will focus on components for the local loop.
- RCA has initiated a multi-million dollar expansion of their laser production facilities near Montreal.
- Toshiba America has introduced a line of 1300 and 1550 nm lasers produced at its Deerfield, Illinois plant.

2.4.6 Forecasts

Of the major characteristics of light sources, the only two sure bets are that longer wavelengths will be used and that higher bit rates will be achieved.

The move to higher wavelengths will probably stop, at least through this century, at 1550 nm. Although transmission at 2000 to 10,000 microns may be possible and even desirable, migration will be hindered by the operators' reluctance to substitute existing silica cable for new fluoride fibers. Also, the commercial availability of light sources to transmit at these much longer wavelengths remains problematic.

The next fifteen years will also see the introduction and wide-scale use of distributed feedback lasers. The narrow

spectral width offered by these lasers will be an important component in the eventual implementation of coherent communications.

Bit rates will continue to rise, although not at the phenomenal pace experienced to date. Expected transmission speeds will be 810 Mbps/1.7 Gbps by 1990, 1.7/4 Gbps by 1995, and 4/8 Gbps by 2000.

Although laser prices will continue to fall, this will have little effect on the future development of long-haul networks. Because lasers are a small proportion of system costs, the decision to upgrade to higher wavelengths or speeds will be based on criteria other than the cost of that single component.

Similarly, the narrowing of the gap between the prices for lasers and edge-emitting LEDs will forestall the substitution of LEDs for lasers. The performance advantages of lasers are just too great to be compensated for by a (decreasing) price differential.

2.5 DETECTORS

A detector performs a complementary function to the source: it converts optical energy (watts) to electrical energy (amps). Requirements for detectors in fiber optic communications include:

- High response to incident optical energy;
- High sensitivity to low level signals;
- Adequate instantaneous bandwidth to respond to the information bandwidth on the optical carrier;
- Minimum internal noise added to the detected signal;
- Low susceptibility to changes in environmental conditions (especially temperature); and
- Low cost.

The most common detectors used in fiber optics links are silicon-based solid state semiconductor PIN and avalanche (APD) photodiodes with useful response in the near-infrared range (800-1200 nm). In long-distance transmission, the choice is between GaInAs PIN and Ge APD detectors operating between 1000 and 1600 nm. Phototransistors and hybrid or integrated devices containing preamplifiers and full receivers are also used.

2.5.1 Research and Development Foci

Until recently, detectors have been one of the more mature and less glamorous of the fiber optic components. Two factors, however, are stimulating new attempts to improve the performance of detectors: new materials and coherent detection.

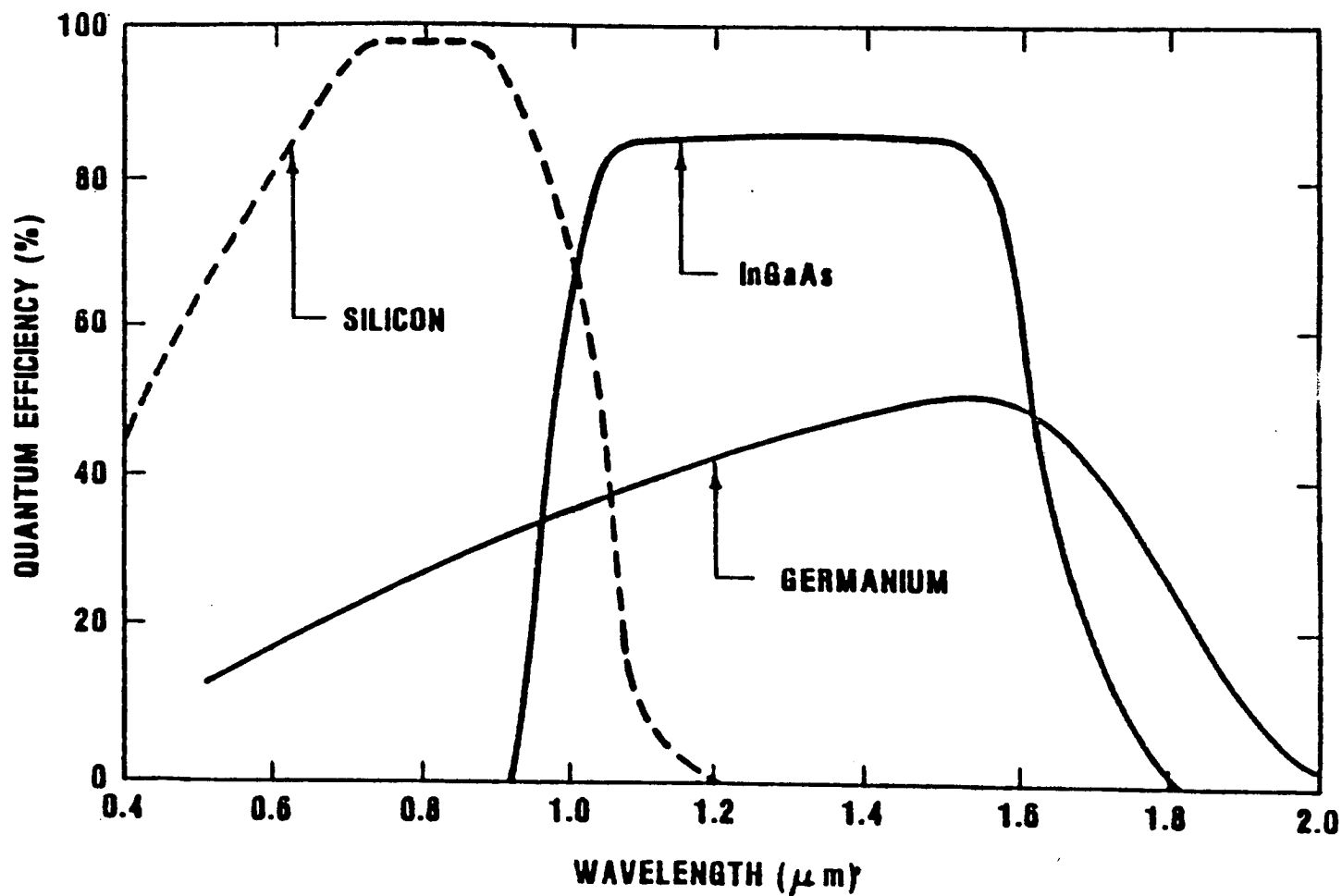
2.5.1.1 New Materials

As shown in Exhibit 2.18, the responsivity of silicon to light is greatest in the region between 600 and 1000 nm. Its quantum efficiency (defined as the ratio of incoming photons to the number of electrons set flowing in the external circuit) drops off sharply at wavelengths above 1000 nm, and is negligible above 1200. The present move to longer wavelengths has therefore necessitated the development of new detector materials.

Work is proceeding on germanium, ternary, and quaternary compounds. Indium gallium arsenide phosphide is currently the preferred material because of superior performance (absorption, quantum efficiency) and decreasing prices.

EXHIBIT 2.18

SPECTRAL RESPONSE OF DETECTOR MATERIALS



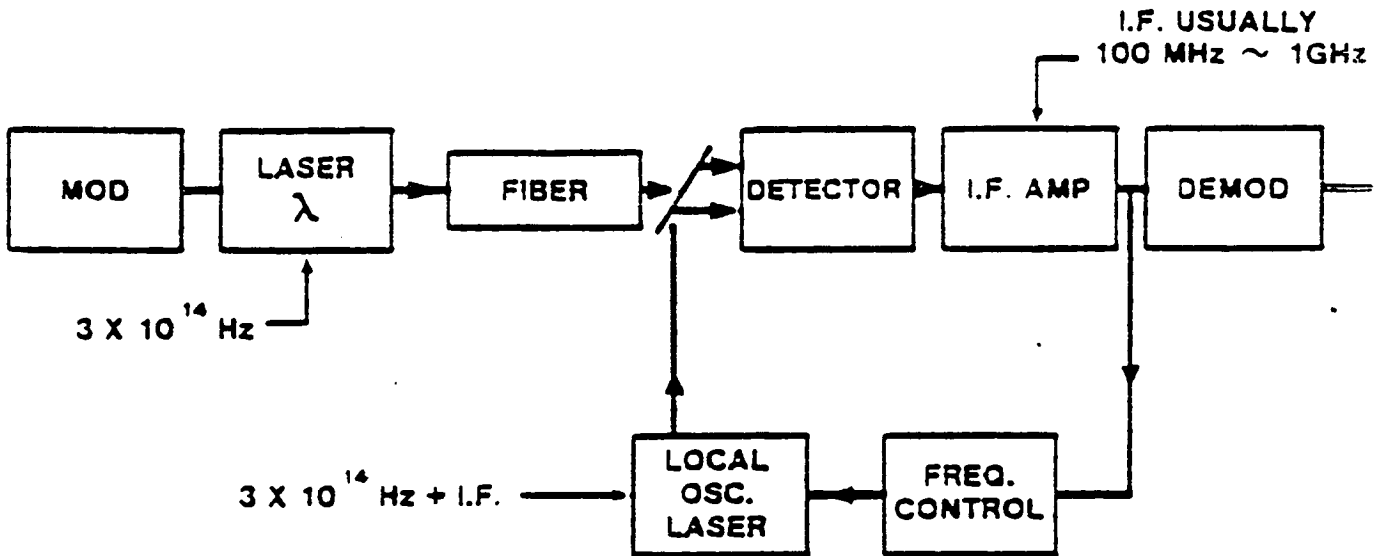
In March 1986, for example, Fujitsu Ltd. started supplying samples of InGaAsP avalanche photodiodes. The company claims the detector can increase by a factor of four the link lengths of 1300 nm systems operating at 405 Mbps. The estimated limit of the device is 2 Gbps transmission operating over a repeaterless distance of 125 to 200 miles. Although currently in development, Fujitsu claims that full-scale factory production is possible.

2.5.1.2 Coherent Communications

Conventional detectors operate through direct detection. Over long distances, this can result in greatly limited sensitivity. Repeaters must be placed periodically in a fiber optic system to boost the light signal strength. The incoming light signal is often still weak, however, with resulting signal losses due to attenuation. However, if detectors were more sensitive to the light signal, the distance between repeaters could be increased.

Coherent communications addresses this problem. Analogous to frequency modulation in radio, heterodyne coherent communications involves mixing the light emerging from the fiber with a beam from a laser of similar wavelength that functions as a local oscillator in the receiver (Exhibit 2.19). A stabilization scheme separates the two laser frequencies by a fixed amount. Under the proper operating conditions, the output of the mixer will be an exact replica of the input lightwave signal at an intermediate frequency. The frequency is equal to the difference between the lightwave signal frequency and that of the local oscillator. When this difference is small -- a few gigahertz or less -- it is a simple matter to amplify and demodulate the mixed output using conventional radio-frequency electronic techniques.

EXHIBIT 2.19
HETERODYNE COHERENT COMMUNICATIONS



One of the primary advantages of coherent detection is a potential 15 to 20 dB improvement in receiver sensitivity. This could increase repeater spacing to 300 kilometers.

In addition to improved sensitivity, coherent detection also provides for greater frequency selectivity, allowing for hundreds of closely-spaced wavelengths to be carried on one fiber. This, combined with the narrower spectral linewidths obtained through improvements in light sources, provides a firm foundation for the development of coherent communications systems.

Work on coherent communications is proceeding at a number of laboratories, with the following results using coherent detection:

- British Telecom Research Labs transmitted a 140 Mbps signal 199 kilometers.
- AT&T Bell Labs send 1 Gbps over 148 kilometers.
- NTT reported 400 Mbps over a 251-kilometer link.

2.5.2 Detector Prices

For both PIN and APD detectors, manufacturing economies of scale have largely been reached and prices have stabilized. For telecommunications-grade APD detectors in quantities of 1000 or above, the price is about \$100 each. For PIN detectors, the price is around \$20.

The price of APD detectors have declined sharply and are now leveling off showing economies of scale around \$20 per detector, as shown in Exhibit 2.20.

PIN detector price trends follow the same trend, as Exhibit 2.21 illustrates. While the telecommunications grade has not yet leveled out the non-telecommunications grade PIN detector is more mature in this sense. For both types of detector the telecommunications grade remains more costly.

2.5.3 Suppliers

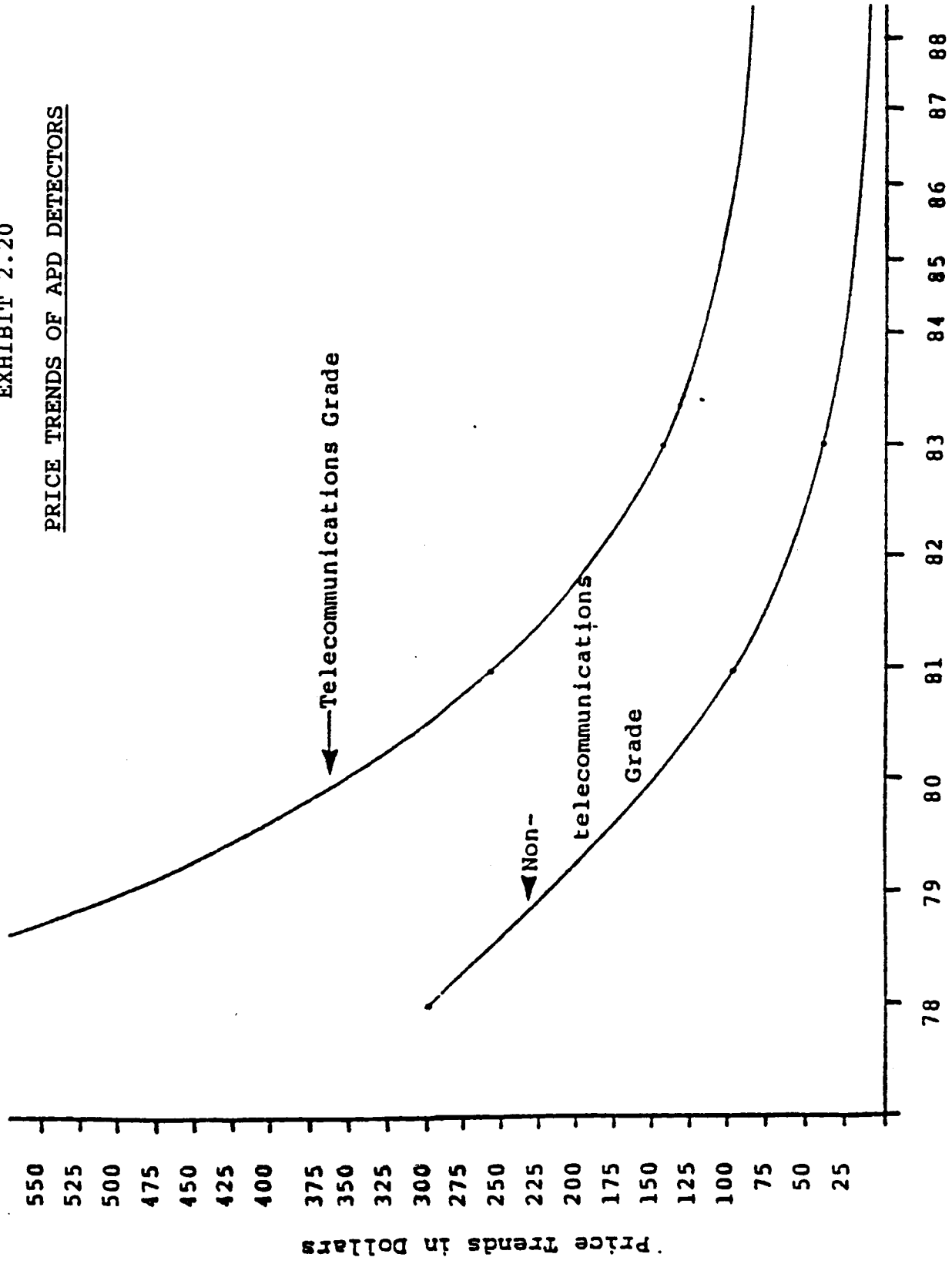
A number of companies are currently supplying detectors for long distance telecommunications systems. Among the principal detector manufacturers are AT&T, Lasertron, NEC Electronics, Fujitsu, and several other Japanese companies.

- Epitaxx, Inc., of Princeton, NJ, produces PIN photodiodes that are GaAsIn-based. Although its product line includes detectors ranging from 800 to 1800 nm, its primary market is fiber optic communications.
- Hewlett-Packard's PIN detectors are based on GaAs (for short-wavelength) and InGaAsP (for 1300 nm) technologies.
- Lytel, Inc. of Somerville, NJ produces an InGaAs PIN photodiode with operational capabilities in the 1Gbps range. Company officials claim high responsivity in the 1000-1600 nm region.

Other suppliers include Opto-Electronics, Ortel Corporation, PlessCor Optronics (a joint venture of Plessey and Corning), General Optronics, RCA, and Siemens AG of Munich.

EXHIBIT 2.20

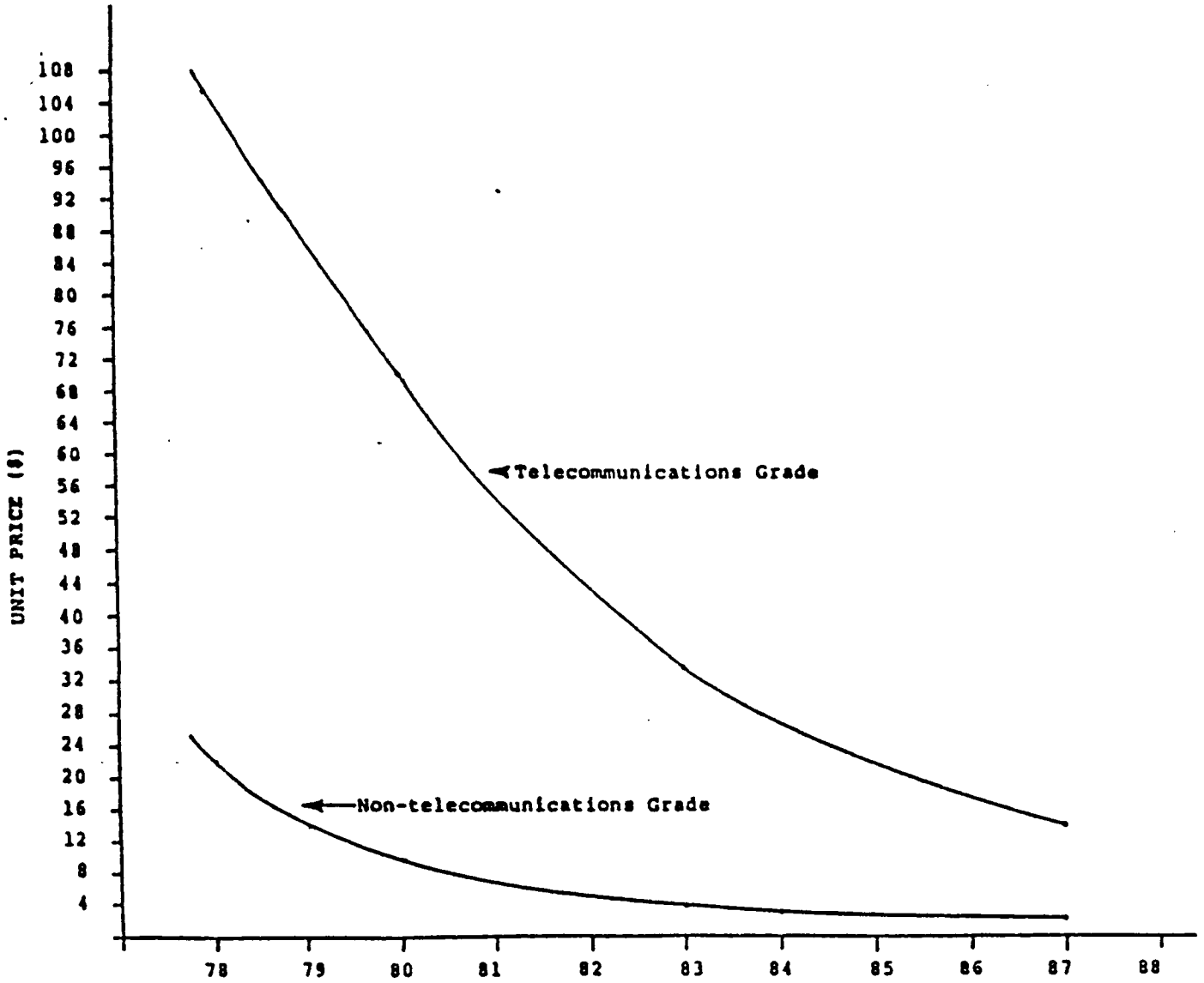
PRICE TRENDS OF APD DETECTORS



Source: Information Gatekeepers, Inc. 1984

EXHIBIT 2.21

PRICE TRENDS OF PIN DETECTORS



Source: Information Gatekeepers, Inc. 1984

2.5.4 Forecasts

Coherent technology is not yet commercially available. Current lasers suffer from frequency instability, intensity noise, and phase noise. The unpredictable polarization of optical fibers also makes it difficult to achieve efficient conversion of incoming optical signals to an intermediate frequency.

We estimate that these problems will largely be overcome within the next few years and that coherent detection will be introduced into long haul networks around 1990. This, along with other technical developments, will allow for repeaterless spans of up to 200 kilometers by 1995 and 300 kilometers by 2000.

2.6 MULTIPLEXERS

To squeeze the most performance out of a transmission medium, significant work is being done on multiplexing, a process that allows more than one signal to be transmitted along a single medium. Obviously, the ability to multiplex is important; inability to do so would mean that each conversation or data link would require its own copper wire or other connection. Discussion in this section will focus on electronic and optical multiplexing.

2.6.1 Electronic Multiplexing

Virtually all multiplexers now operate electronically. The mechanism by which this multiplexing works can vary. In time division multiplexing, the signals from several sources share the circuit by using the circuit in successive time slots; synchronizing pulses are used to assist in demultiplexing at the distant end of the circuit. In frequency division multiplexing, the available transmission frequency range is divided into narrower bands, each of which is used as a separate channel.

The basic unit of multiplexing is the D channel bank, which combines 24 voice channels for transmission over 1.544 Mbps T1 lines. The M12 digital multiplex combines four T1 streams into a 6.3 Mbps T2 channel. The M23 mutliplex combines seven T2 streams into a single 46.3 Mbps pulse stream. Additional multiplexes can be used to form even larger pulse streams.

In optical transmission, the combined signals from the multiplexers is converted to an optical signal and transmitted over the fiber. At the receiving end, a complementary process breaks the multiplexed transmission down into its constituent signals. Even when carried by lightwave systems, therefore, these multiplexers still rely on electronic techniques. Unfortunately, the conventional silicon-based multiplexers operate too slowly to be effective above bitrates of 565 or 810 Mbps.

One solution to this problem is the development of new materials that would allow electronic multiplexing to occur at faster speeds. AT&T Bell Labs, for example, announced at the Optical Fiber Communication meetings in 1986 the use of gallium arsenide devices and a 1500 nm laser to electronically multiplex up to the 4 Gbps level over 103 kilometers of single mode fiber.

2.6.2 Wavelength Division Multiplexing

Another solution to the problem of combining signals at high speeds is through the multiplexing of optical beams of different wavelengths. Light of different wavelengths propagate without

interfering with one another, so several channels of information (each having a different carrier wavelength) can be transmitted simultaneously over a single fiber, thereby increasing its information capacity. This process, called wavelength-division multiplexing (WDM), is essentially the extension of frequency division multiplexing to the optical domain.

The operation of a WDM device is shown in Exhibit 2.22. An optical multiplexer couples light from the individual sources to the transmitting fiber. At the receiving end, an optic demultiplexer separates the different wavelengths before photodetection of the individual signals.

There are numerous advantages to the use of WDM:

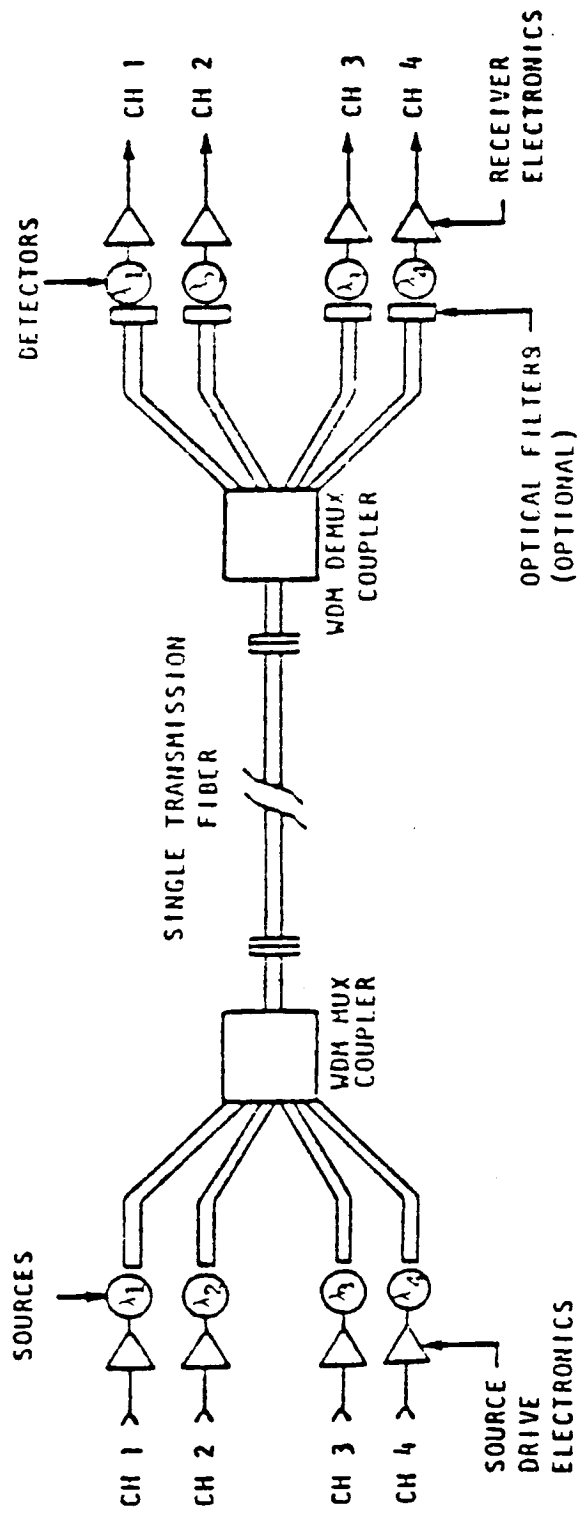
- By using N wavelength channels, the transmission capacity of each fiber is increased by a factor of N;
- Signals of various modulation modes, e.g. analog or digital, can be transmitted simultaneously without elaborate electronics;
- In contrast to electrical multiplexing, the source power is not distributed among the channels, leading to a significantly improved signal-to-noise ratio;
- The transmission capacity of existing routes can be significantly increased; and
- WDM devices are cheaper, smaller and more reliable than the comparable electrical multiplex units.

Among the problems and disadvantages being experienced by WDM techniques are:

- The present insertion loss is high, leading to a shortening of link lengths;
- Spectrally-graded transmitter diodes are expensive;
- It is difficult to attain the high cross-talk attenuation required with simultaneous narrow channel spacing; and
- At present, the savings obtained through fewer fibers and electronics are insufficient to compensate for the additional WDM costs.
- The abundance of capacity on existing lightwave systems has not made it necessary to resort to WDM techniques for enhancing fiber capacity.

EXHIBIT 2.22

WAVELENGTH DIVISION MULTIPLEXING



Source: Information Gatekeepers, Inc. 1985

2.6.3 Research and Development Foci

There are currently two technical issues affecting the use of wavelength division multiplexing.

First, the relatively wide spectral linewidth obtained even with the use of lasers makes it difficult to "stack up" numerous wavelengths without some overlap and interference. The transmission of very narrow-width wavelengths would allow hundreds, even thousands, of closely-packed signals to be transmitted. Work focusing on this problem, involving the development of distributed feedback lasers, has been described in Section 2.4.3.1.

Second, the current generation of receivers are not capable of detecting such closely packed signals of slightly different wavelengths. As we have seen in Section 2.5.1.2, new methods of coherent transmission and detection are being developed to overcome this problem.

A significant development in WDM techniques was announced in March 1986 by the Electron Devices Laboratory at Toshiba Corporation's Research and Development Center. The laboratory had succeeded in multiplexing and demultiplexing five closely spaced optical signals on one fiber. Existing WDM systems utilize wavelength spacing on the order of 100 nanometers. In the Toshiba trial, the signals were spaced only 5 nanometers apart, a significant improvement over the 10 nanometer spacing that had hitherto been achieved. All five wavelengths were in the 1300 nm window, thereby allowing them to travel long distances together. Toshiba researchers utilized five distributed feedback lasers manufactured from gallium indium arsenide phosphide/indium phosphide by conventional fabrication techniques.

In another development also announced in March 1986, Plessey Research claimed the first multiplexing of 40 separate optical signals. Using 40 different LEDs, the signals were drawn from only five differing variants of the infrared part of the spectrum. Each of these five were then further subdivided into 8 wavelengths through a technique known as "spectrum slicing."

2.6.4 Forecasts

The most important question affecting the use of wavelength division multiplexing is its economics. Given the rapid increase in transmission speeds, is there a need for a technique that can increase bitrates even further? And even if the answer is yes, can it be cost-justified?

When AT&T constructed its Northeast Corridor, the first of the fiber optic long distance links, it made provision for

transmission at three wavelengths. At that time, transmission was at 45 Mbps, and there was perhaps a need to increase capacity through WDM. With the move to higher speeds, that need was effectively eliminated. It is an indication of the economic unattractiveness of WDM that the technique has not been applied to any of AT&T's other routes or by any other long-distance carrier.

We anticipate, therefore, that through the 2000 timeframe, WDM will not be utilized in long distance fiber optic networks. This is because (1) the increase in transmission speeds will more than match the demand for bandwidth, and (2) compared to other means of increasing bandwidth, WDM will continue to be cost-ineffective.

2.7 SWITCHING

At present, switching is done electronically, which entails the conversion of optical signals to and from electronic signals so that switching can occur. If the present trend toward very high-speed communications systems continues -- as we expect that it will -- severe problems will be experienced in using electronics to process and switch signals. Greater speed and economies could be achieved if switching were done optically.

As a result, work is proceeding on the development of an all-optical switch.

- Bell Labs has placed 16 directional couplers on a single chip of lithium niobate. The 4 input x 4 output switches utilize channels of titanium that come close to each other at 16 points. Altering the voltage driving the couplers forces light to jump the narrow gap between channels, thereby switching the signal.
- Researchers at the Tokyo Institute of Technology have developed a "quantum well" structure that may allow up to 300 optical switches to be placed on a single chip. The quantum wells are created by stacking alternate layers of InGaAsP and InP. Activation time is reported to be one 10-trillionth of a second.
- Ericsson has developed an 8 x 8 optical switch that it claims is the most complex integrated circuit in the world. The lithium niobate device incorporates 64 switching elements known as operational direction couplers. Intended for use with single-mode fiber, it offers virtually unlimited bandwidth for data stream switching.

Broadband switches are now being developed by Bell Labs, NTT, Siemens, and SEL to switch 140 Mbps. It is expected that these switches will be available within the next five years.

It is important to note that the switches developed thus far can switch only streams of messages; they cannot switch individual messages within those streams.

An optimistic forecast for the development of an optical switch capable of switching individual messages would place commercialization and implementation in the mid-1990s. A conservative forecast would not anticipate development until well into the next century.

Most realistically, we expect that optical switches will be available around the turn of the century, too late to be an important factor within the time frame discussed here.

2.8 SUMMARY OF TECHNOLOGY ELEMENTS

All of the components discussed in this chapter are the focus of research and development programs. Many of these efforts will lead to higher performance characteristics; others will be abandoned before they are applied. This final section summarizes fiber optics technology by discussing uncertain technology elements and forecasts of future system capabilities.

To talk about uncertain technology elements at all is misleading; it conveys the impression that fiber optics is somehow untested. The truth, of course, is that the technology is tried and true. What is uncertain are the future performance characteristics of individual components and the overall configuration of fiber optic systems. Yet whatever the specific outcomes of some of these R&D foci, it is certain that the overall result will be high bit rate systems at lower cost.

Greatest uncertainty is associated with such developments as:

- the evolution to higher bit rates above 1 Gbps;
- the adoption of distributed feedback lasers;
- the adoption of fluorine fibers; and
- the implementation of coherent systems.

Optimistic projections would dictate that the long distance fiber optic systems of 2000 will operate at speeds of over 10 terabits. With the utilization of long wavelengths and fluoride fibers, transmission would span the continent without repeaters. Narrow linewidth lasers, coherent communications, and wavelength division multiplexing would allow hundreds of channels to be transmitted over each fiber. In short, the optimistic forecast envisions near-fulfillment of fiber optics' potential as a limitless low-cost transmission medium. This scenario is unlikely primarily because the demand for such extraordinary bit rates will not materialize and will not provide an acceptable rate of return.

The pessimistic vision sees stagnation of the technology at or near present levels. Bit rates would remain at 1.6 gigabits, and much of the technology that would allow for longer repeater spacings -- e.g. coherent communications and narrow-linewidth lasers -- would not be commercialized. This scenario is unrealistic because the dynamics of both the fiber optics and long distance industries are pushing toward the development and implementation of faster and more powerful technologies.

A more realistic scenario is based on the analysis presented in Section 1.4. Among the technology elements we see being implemented by long distance networks are:

- Bit rates of 810 Mbps/1.7 Gbps by 1990, 1.7/4.0 Gbps by 1995, and 4.0/8.0 Gbps by 2000.
- Introduction of coherent communications and narrow linewidth lasers by 1990.
- Repeater distances of up to 100 kilometers by 1990, 200 kilometers by 1995, and 320 kilometers by 2000.

Other technologies, such as wavelength division multiplexing and new fiber materials, will not be routinely implemented because of both the costs involved and the lack of demand.

SECTION 3.0
FIBER OPTIC LONG DISTANCE SYSTEMS

3.1 OVERVIEW

The long distance service market, defined as inter-LATA communication traffic, is growing approximately 7.8 percent annually. It is projected that revenues will climb from \$57.6 billion in 1985 to \$78 billion in 1989.

To service this traffic, and to benefit from this large and lucrative market, a number of long haul fiber optic networks are being implemented. As shown in Exhibit 3.1, there are four nationwide systems currently under construction. Nine regional systems are anticipated. That number that climbs to 16 if the seven members of one nationwide consortium (NTN) are counted.

The total number of announced route miles is astounding. If constructed as planned, long haul fiber optic networks in this country will cover over 60,000 route miles. Not surprisingly, most of the networks will concentrate on the eastern half of the country, as over two-thirds of the communication traffic is derived from this region. Potentially, this could lead to service gluts in several cities where at least three fiber optic networks will be fighting for customers.

Over one-third of the proposed networks, comprising over 20,000 miles, have been cutover. If construction schedules are maintained, this percentage will climb to over seventy-five percent by the end of 1986.

A number of factors are responsible for this steady growth in the long-distance market: population increase and mobility, increased demand for business communications, and greater popular acceptance of low-cost telecommunications. Another impetus for the more recent boom in long haul communications has been deregulation and the entry of new carriers.

3.2 THE IMPACT OF DIVESTITURE AND DEREGULATION

Although the break-up of the Bell System was the most dramatic of the moves to open the telecommunications market to competition, deregulation of the industry and a commitment to increased competition have been the motivation for a number of judicial, congressional and regulatory decisions.

In 1956, a Consent Decree between AT&T and the Justice Department restricted AT&T to the provision of only regulated telephone services. For a number of reasons, however, this arrangement proved unsatisfactory. AT&T, for its part, was dissatisfied with its exclusion from the data processing services and equipment market. Losing out on these lucrative

NETWORK	LENGTH (MI)	MAJOR OWNERS	SUPPLIERS	COUNT	BIT RATE	COST	TOTAL CUTOVER MILLS
NATIONWIDE:							
AT&T	10,200	AT&T	AT&T Technologies, Philips, R-C**, Telco Systems, NEC	24	40, 405, 417, 565	several \$100 million	5,200
MCI	7,000	MCI	Siecor, Northern Telecom, R-C, Fujitsu	6, 22, 44***	405	\$600-700 million	2,500
NTN:							
Consolidated Net	730	Consolidated Communications	Northern Telecom, R-C	12	565	NA	300
LDX Net	2,200	LDX Group	Ericsson, AT&T Tech., Pirelli, Siecor, Fujitsu	24	565	\$110 million	600
Lifel	1,600	Several Private Investors****	Pirelli, Northern Telecom, SAI	18	140-565	\$77-85 million	675
Microtel	1,300	Microtel	Ericsson, NEC, ITT	10	405	\$60 million	731
SouthernNet	1,500	E.F. Hutton and Independent Telcos	Siecor, AT&T, Ericsson, NEC	10	405	\$70 million	331
Southland Fibernet	330	Southland Communications	Ericsson, NEC	10	405	NA	272
Wiltel	3,500	Williams Co./TS&S	Siecor, NEC	10	405	\$100 million	214
U.S. Sprint	23,000	GTE/U.S. Telecom	Ericsson, General Cable, Siecor, Fujitsu, Stromberg Carlson	6-32***	565	\$2-4 billion	6,200
REGIONAL:							
Bandwidth Technologies	300	Optinet, Inc.	Northern Telecom	18	565	\$21 million	100
Digi-Net	900	Private	AT&T Tech., Northern Telecom	32	405	\$65 million	550
Electra	550	Cable & Wireless/MKT Railroad	Fujitsu, Telco Systems, AT&T Tech.	16-24***	405	\$50 million	550
Indiana Switch	733	27 Independent Telcos/U.S. Switch	Not Announced	6-22 (est)	560	\$23 million	0
ICC	109	ICC	Not Announced	25-47***	140	\$19.9 million	0
Lightnet	5,000	Southern NE Telephone/ESX Corp.	AT&T Tech.	38-48***	90-417	NA	700
Mutual Signal	404	Walker Telecommunications	Siecor, NEC	10	565	\$30 million	0
Norlight	550	Five Midwest Utilities ****	Alcoa/Fujikura, Philips, Ericsson	12	130-565	\$33 million	0
RCI	580	Rochester Telephone Corp.	AT&T Tech., Fujitsu	24	405	\$90 million	580
TOTALS:	60,486					\$4,902.9 million	20,503

*** varies from different segments
 **** detailed in profile, too numerous to list

NA = Not Announced
 * rounded

** R-C = Rockwell-Collins

FOLDDOUT FRAME

opportunities was becoming all the more galling because, due to technological advances, the already fuzzy boundaries between regulated telecommunications and unregulated data processing services were becoming increasingly arbitrary. Other communications vendors were unhappy with their own inability to enter the telecommunications market. Users, for their part, were dissatisfied with what they saw as AT&T's unresponsiveness to their needs and with a pricing structure that did not reflect the actual costs of providing services. The situation reached a head in 1974, when the Justice Department, charging the company with using its monopoly to limit competition, brought suit against AT&T.

In an attempt to clarify that fuzzy boundary between telecommunications and data processing services, the Computer Inquiry II decision in 1980 distinguished between two types of services: basic and enhanced. "Basic services", involving the transmission of information (such as telephony) would continue to be regulated. "Enhanced services", requiring the restructuring, processing, or reformatting of information (e.g. data processing and electronic mail) were deregulated. Regulated carriers seeking to provide enhanced services had to do this through separate subsidiaries.

Also as a result of the FCC's Computer II Inquiry, customer premise equipment (CPE) was fully deregulated, a process begun in 1968 with the Carterfone case. The deregulation of enhanced services also meant that AT&T could offer computer services and equipment, a market from which it had previously been barred. In May of 1986, the FCC ruled on its Computer Inquiry III, in which the separate subsidiary requirement was abandoned.

In January 1982, AT&T and the Justice Department reached a settlement of the AT&T anti-trust case. Under the agreement, AT&T was allowed to enter the unregulated computer, data processing, and enhanced network markets. It also retained its long distance network, Western Electric (now AT&T Technologies) manufacturing facilities, and Bell Laboratories. In return, AT&T divested itself of 22 Bell Operating Companies (BOCs), thus effectively removing AT&T from the local exchange telephone business. The BOCs, owned and operated by seven Regional Holding Companies (RHCs), are now the primary suppliers of local voice telephone services within their geographic areas.

Divestiture and deregulation has fostered a new era of competition in the long distance (and other telecommunications) markets. Five national and 16 regional companies have initiated or expanded networks in an attempt to win some of AT&T's long distance business. As service rates declined, inter-LATA traffic has increased, creating a larger revenue pie.

So far, these alternative long distance carriers have not been particularly successful in carving out a larger piece of this expanding pie. In 1985, only two of the leading alternative carriers individually garnered any significant market share; MCI earned 4.7 percent of the total revenue and GTE Sprint earned 1.9 percent. The remaining independent carriers combined received 6.2 percent of the market; despite their efforts, AT&T still remains the overwhelmingly dominant force in long distance transmission service.

But it ain't over 'til it's over, and the end of the struggle for the long-distance market is nowhere in sight. The long haul industry is presently in a state of ferment, with carriers consolidating, expanding, or falling by the right-of-wayside.

3.3 THE USE OF FIBER OPTICS IN LONG HAUL NETWORKS

One strategy being used by all of the carriers in their attempts to gain a competitive edge is the implementation of fiber optics in their networks.

Given the narrow bandwidth of copper wire, the signal delays and overcrowded radio spectrums encountered with satellites and digital microwave, carriers are turning to fiber optics to handle the growing long distance traffic. Indicative of this trend is both AT&T's and MCI's growing commitment to fiber optics. As Exhibit 3.2 illustrates, both carriers plan to make fiber optic their primary transmission medium by 1990.

This industry-wide enthusiasm has helped optical fibers to infiltrate the long distance networks faster than anticipated. For example, in 1980, Future Systems, Inc. predicted that only the Northeast corridor would be "fiberized" by 1985. In each of the maps pictured in Exhibits 3.3 through 3.6, the first date indicates that firm's estimates for network completion, the second date shows the actual completion date. Although the study was done only a few years ago, it wildly underestimated the construction of fiber networks. As we can see, the industry has already reached their projected 1995 levels.

This rapid installation of fiber in long haul systems has helped to drive the U.S. fiber optic market at a frantic pace; by 1989 it will exceed \$1.6 billion. The market for cable alone will soar. Growing 66.3% annually, the factory value of worldwide shipments from major U.S. cable manufacturers will rise from \$135 million in 1983 to over \$2.8 billion in 1990.

EXHIBIT 3.2

SHIFT OF TRANSMISSION MEDIA FOR TWO MAJOR NETWORKS

(Percent of Total Route Miles)

	<u>AT&T</u>	
	<u>1984</u>	<u>1990</u>
Microwave	33	25
Copper Wire	35	20
Coaxial Cable	10	10
Satellite	12	4
Fiber Optics	10	41
	<u>MCI</u>	
	<u>1984</u>	<u>1990</u>
Microwave	99	40
Fiber Optics	1	60

SOURCE: IGI Consulting, Inc.



EXHIBIT 3.3

FIBER OPTICS SYSTEM GROWTH IN THE U.S.

Projected: 1985 -- Actual: 1983

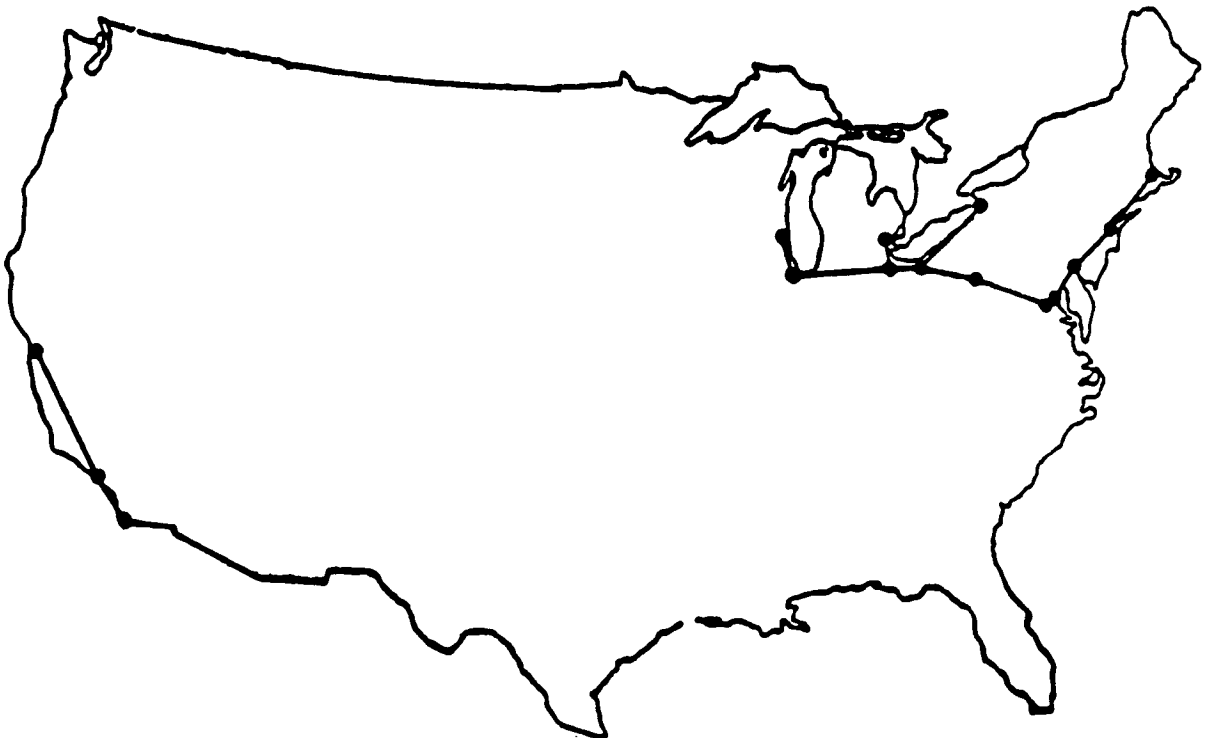


EXHIBIT 3.4

FIBER OPTICS SYSTEM GROWTH IN THE U.S.

Projected: 1990 -- Actual: 1984

Source: Future Systems, Inc.



EXHIBIT 3.5

FIBER OPTICS SYSTEM GROWTH IN THE U.S.

Projected: 1995 -- Actual: 1985

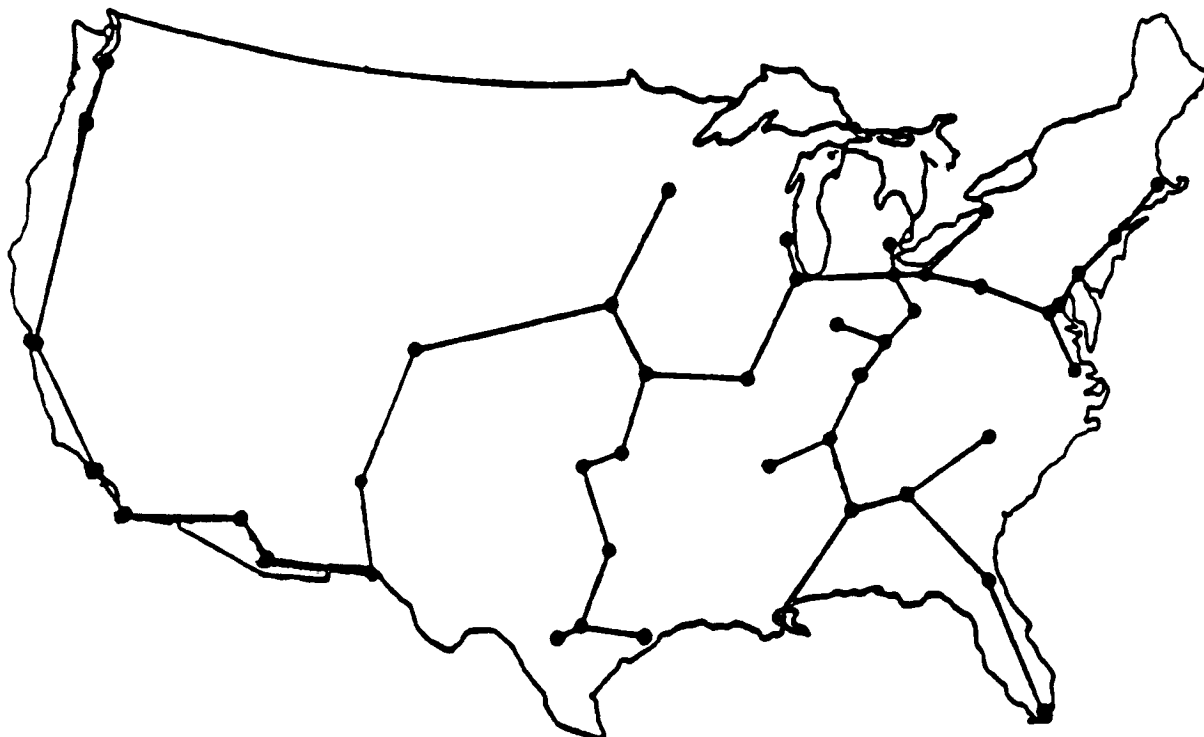


EXHIBIT 3.6

FIBER OPTICS SYSTEM GROWTH IN THE U.S.

Projected: 2000 -- Revised: 1990

Source: Future Systems, Inc.

3.4 MARKET TRENDS AND ISSUES

While the use of fiber optics as a transmission medium is an important and necessary element in any carrier's strategy for success, it is not the only factor affecting the evolution of the long distance market. As networks become operational, carriers are faced with the challenge of gaining customers to utilize their service and generate revenue. Already one network has fallen by the wayside due primarily to financial troubles; Fibertrak had originally planned to build a nationwide network, but has been forced to delay construction indefinitely. Other networks are resorting to several regrouping strategies to ensure the success of their networks.

The remainder of this chapter will explore of other issues that will affect the fortunes of individual companies and the shape of the entire industry. These issues include:

- Consolidation
- First-in-Ground Factor
- Overcapacity
- Rights of Way
- Exploitation of Secondary Markets

3.4.1 Consolidation

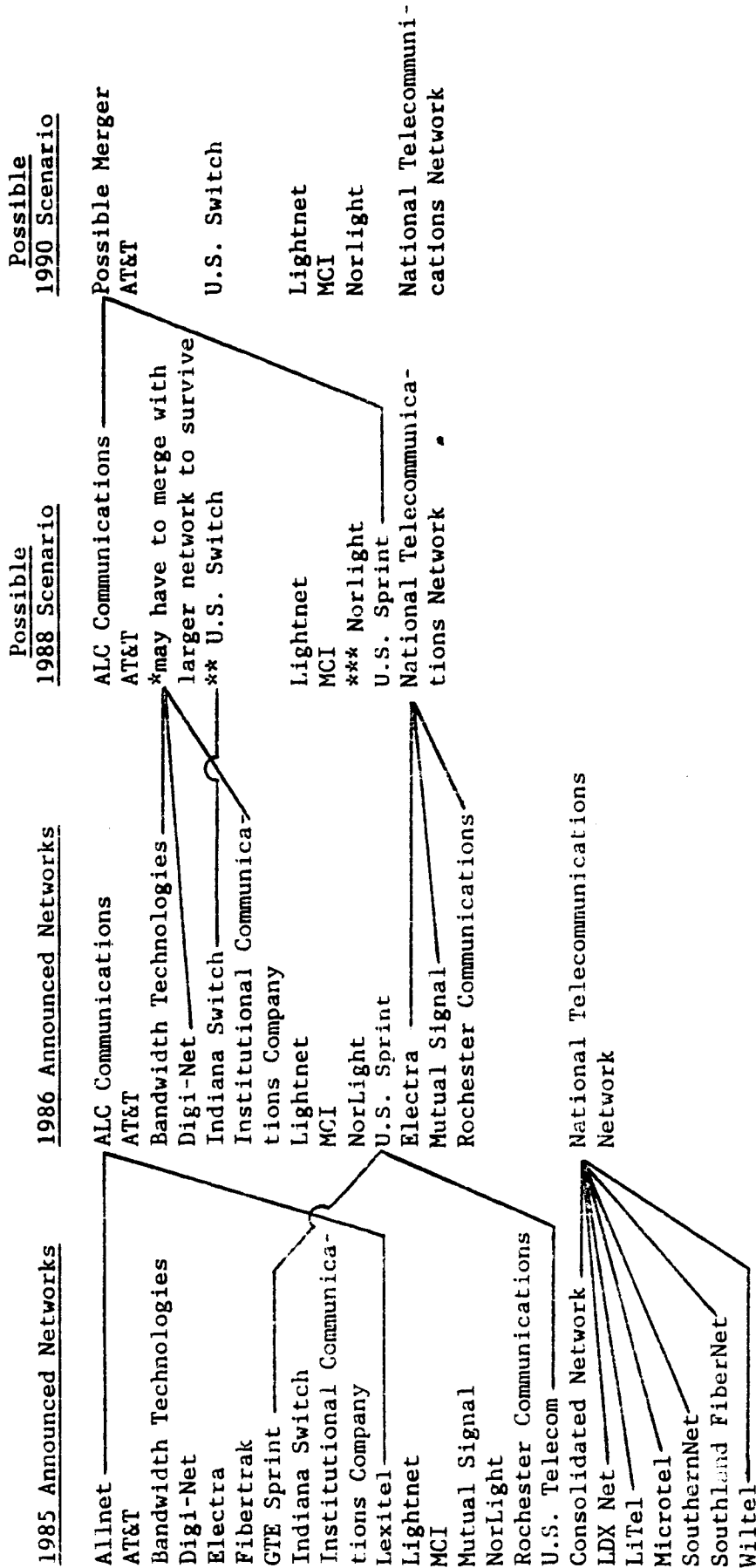
The initial rush of entrants into the long distance market has led to reconsideration by many carriers of their ability to go it alone in the competitive field.

As Exhibit 3.7 illustrates, the key players in the long haul industry have undergone a considerable shake-up over the past year. Mergers and consolidations have been the rule of the game despite predictions of the huge profits to be gained from this industry.

Part of this can be attributed the nature of the industry -- a tale of one Goliath vs. many little Davids. AT&T is considered the competitor to beat and many of the smaller carriers, in the hope of launching an effective offensive to gain market share, are consolidating their resources. U.S. Sprint, the merger of the third and fourth alternative common carriers in this country, is highly indicative of this trend. While on its own, each has managed to carve out only a small piece of the long distance pie. The two companies are hoping that the sum of the parts is greater than the whole, and that the resulting synergy will lead to a more substantial share of the market.

EXHIBIT 3.7

CONSOLIDATION OF LONG HAUL FIBER OPTIC NETWORKS



* may not have capital or marketing clout to survive alone

** now that FCC has approved Indiana Switch, company plans to try to expand concept to other states

*** pending FCC approval, approval could also stimulate networks of similar nature

Other firms have recognized the great expense associated with constructing their own networks and are consolidating resources without an actual merger. Many are now electing to lease capacity from other systems as a means of expanding their service area without actually installing any cable or building any additional facilities. Rochester Communications Corporation (RCI), for example, has built its own fiber optic network through the Midwest and New York State. To further expand its long distance service, the company has elected to lease capacity from other networks. Service from New York to Washington D.C. has been provided by leasing capacity from Lightnet. In addition, RCI has expanded its long distance fiber optic service to Atlanta with its agreement to share capacity and facilities with SouthernNet, a regional network serving Southeastern United States, from Washington to Atlanta. Other fiber optic networks have also inked similar agreements.

In a very recent agreement, three long-distance companies -- Argo Communications of New Rochelle, NY; Microtel, Inc. of Boca Raton, FL; and Litel Telecommunications Corp. of Worthington, OH -- have merged their operations. The new company, to be called LAM Co., covers over sixty metropolitan areas and is expected to be the country's fourth largest long distance carrier.

The most important consolidation has occurred with the creation of the National Telecommunications Network (NTN), a consortium of seven long haul carriers: Consolidated Network, LDX Net, LiTel, Microtel, SouthernNet, Southland Fibernet, and Williams Telecommunications. While maintaining their own regional fiber optic networks, members will interconnect at designated cities to provide their customers with national service. By pooling their limited resources and routes, members feel they can compete on a more equal footing with giants such as AT&T and MCI.

Consolidation could also be considered a long term move against price wars. With the high cost of cable installation and the low variable cost of serving new customers, fiber optic networks will have every incentive to slash service prices in order to fill the considerable fiber capacity they offer. In many major cities, more than one competitor is scheduled to install their own line. Consolidation reduces this overcrowding since partners will want to cut out duplicating lines. By reducing the number of competitors, the fight for customers is weakened.

Consolidation may also be arranged to serve a special purpose. Electric power utility companies and small independent telcos have formed consortia in order to build a fiber optic network for their own special purposes.

One final factor encouraging consolidation could be the lukewarm reaction experienced by the fiber optic networks constructed so far. Customers do not want to subscribe to an uncompleted network offering a limited service area. Prospective customers also want to be confident that the carrier they choose will still be operational in 10-20 years. By working together, different partners can work simultaneously on their portion of the network and finish the construction of the whole system faster. This goal, as discussed below, is considered imperative to many service operators.

3.4.2 First-In-Ground Factor

When a company is shopping around to select the fiber optic carrier to handle its communications traffic, it is far easier to sell them an operational system. As one network owner summarized, "My best promotional tool was a photograph of our construction crew laying the fiber optic cable." It promotes confidence in the network's longevity if the customer knows that the carrier has financial and organizational resources to at least start construction of the system. From the telecommunications manager's point-of-view, it is easier to sell to upper management an existing fiber optic network than one just on the drawing board.

Many competitors believe that the first operational network in a given area has an unbeatable headstart in gaining customers. Much like the cellular mobile radio market, the first on-line system attracts all the customers and forces any johnny-come-latelies to either develop new markets segments or try to steal competitors' customers. Despite this tough talk, first-in-ground does not seem to scare off any operators. Usually when one service has been cutover in a city, competitors have continued with their installation plans. Nonetheless, some operators believe that the first on-line service would probably have the competitive edge in the case of overcapacity or a price war because of their already built-up customer base.

Fibertrak presents a good example of a network whose demise can be attributed to late timing. Difficulty in signing up customers created financial problems and delays in network construction. Meanwhile, competitors had already cut over significant portions of their networks, therefore raising questions about the need for Fibertrak at all. As more systems are cut over, the chances for Fibertrak's survival grow dimmer.

An important point to make is that some operators do not necessarily have to be first-in-ground with fiber cable. Those companies that already offer telecommunications services can also be considered to have an advantage over those just jumping into the fiber optic business cold. Major operators, like AT&T, already have a customer base from which to sell this new service

as opposed to starting from ground zero in their search for customers. They already have a revenue base, established reputation and alternative services and once fiber optic service becomes operational they can just switch current traffic over or decide to market it as a special, premium service.

The National Telecommunications Network (NTN) is a consortium of regional carriers that firmly believe in the first-in-ground strategy. Comprised of carriers currently offering long distance service and some telecommunications newcomers, all six members are working on their separate network links and hope to interconnect at various cities. By the end of 1986, NTN hopes to reach 60 to 100 percent of the LATAs in the continental United States. They feel that the great capacity of the first cable combined with the head start on customers and cash flow makes it difficult for any competitors to cost justify construction of a duplicate link.

3.4.3 Overcapacity

Because of the advances in optical technology and the completion of new fiber networks, the end of the decade should witness at least a five or six fold increase in long distance communications capacity in the United States, perhaps even topping 10 billion circuit miles.

The rush to build all this capacity can best be explained if one looks to the pre-Bell breakup days. Many telecommunications veterans can remember all too vividly the grief when trying to obtain circuits from Ma Bell in her monopolistic heyday. They feel that the key to survival is the construction of their own facilities as they can control the flow and quality of their own service.

The question currently arising is whether there is a need for all this capacity now on the drawing boards. Fiber optic technology is constantly improving. Transmission speeds are expected to increase from the 565 Mbps systems in operation today to 1.2-1.7 Gbps by 1987 and climb to 2.2 Gbps by 1988, thus increasing the amount of data that can be transmitted over a single fiber.

Some industry analysts (especially within the carrier community) are promoting the scenario that new products can create new needs. They point to how the interstate highway system stimulated the demand for cars and trucks because of the increase in drivable highway miles. Closer to home is the development of the mainframe computer. When it was first developed, IBM predicted that the total worldwide demand for the mainframe was 50 units, a wildly inaccurate projection. When some fiber optic local area networks were installed within a company, some corporate skeptics wondered what the company would

do with all the potential capacity of its new system. Now they are learning that both voice and especially data transmission levels have increased as the company discovers new ways to utilize the capacity of the optical fiber system.

By analogy, it is argued that future services and technological developments may also help to fill the long haul cables currently in the planning stages. Video services aimed at both residential and corporate customers and the growing automation of even small businesses are just two areas that could increase the demand for fiber optic capacity.

Industry participants are making adjustments, however. Many network operators, who are now adopting to the deregulatory environment and learning firsthand about the prohibitive construction costs of optical cable installation, are leasing capacity from other carriers as opposed to constructing their own circuits. There already has been a decrease in the average fiber count per cable as operators move to take advantage of optical fibers' broad bandwidth.

Supply and demand could be considered the key. There will always be a need for transmission capacity as companies automate their business and begin to use larger bandwidth services like facsimile and video conferencing. If demand levels are not high enough to warrant all the proposed fiber capacity, the current consolidation trend will most likely continue.

3.4.4 Rights-of-Way

Rights-of-way have proven to be a valuable commodity in the long haul fiber optic market as they provide the operator legal access to the route where they want to lay their cable. Networks were scrambling to secure rights before competitors in an effort to gain the most direct and easiest route to construct. Most of the wheeling and dealing has been completed as network systems have moved past the planning stages and into the building phase.

Highways, utility lines, and underground conduits are all likely places in which operators lay their cable. Gaining the rights-of-way are often one of the most tedious and expensive tasks in the route planning process as operators must negotiate to gain access to the property.

Railroads have discovered their railroad beds are a valuable source of revenue. The beds, which were originally designed for the level ground required for the railroad tracks, are perfect to lay fiber optic cable: it is easy to install the cable along the railroad track, the routes ususally provide direct connections to cities, and it is generally easy to build repeaters along the track.

Different railroads have chosen different ways to cash in on their rights-of-way. Some railroads, like CSX, established fiber optic system joint ventures with communications companies and provide the rights-of-ways. Others, like Conrail, have also gained a new communications network as part of their rights-of-way agreement with a long haul operator. As part of the bargain, Conrail received sole use of a fiber pair for their private communications needs.

To illustrate just how competitive the process to secure rights-of-way is, the U.S. Department of Transportation recently ruled that fiber optic cable can not be laid along the New York State Thruway. Five communications companies including AT&T, Lightnet, Continental Telecom, Western Union, and New York Telephone had expressed interest in using these rights-of-way for their fiber optic systems.

3.4.5 Exploitation of Secondary Markets

With the large operators such as AT&T and MCI fighting to maintain or establish their national networks, other carriers have sought to establish their profitability in secondary, or niche, markets.

Some operators, for example, see an opportunity in the delivery of fiber optic services to smaller cities. Municipal and county governments, regional companies, and smaller universities are some of the institutions that are often overlooked by the long-distance giants but which would benefit from optical connections. Examples of carriers employing this strategy include Consolidated Net in Illinois, Digi-Net in Wisconsin, LDX Net and SouthernNet in the southeast, and Microtel in Florida.

Other companies have decided to construct fiber optic networks for reasons other than the provision of general communications services. For example, Norlight, a consortium of utility companies, has decided that building its own network would kill two birds with one stone: the creation of a private communications network for their own purposes and the leasing of remaining capacity to other parties.

It will be interesting to observe NorLight's development and its impact on the long haul fiber optic industry. Theoretically, it could provide an ideal means by which to bring fiber optic technology to areas currently bypassed by major long haul services. The routes are already laid out; the companies just have to follow the utility lines. The power companies also generally have the required capital available to build such a network.

Perhaps in anticipation of such a developing market, several joint ventures have been announced to produce hybrid cable for the transport of both electrical and optical transmission: Siecor/Kaiser, Fujikura/Alcoa, and Ericsson Lightwave/Reynolds.

While utilities may have the right-of-ways, many lack the experience to construct a communications system. One consortium, Indiana Switch, seeks to address this problem. This company comprises small independent telcos in Indiana who have joined with an investment firm to combine the financial and technical resources to develop a fiber optic network. Besides bringing fiber optics to smaller cities and towns in Indiana, the consortium also wants to accelerate equal access and to incorporate one central switch from which all long distance traffic would flow.

The role of both federal and state agencies in the development of these niche markets cannot be underestimated. While the Indiana Switch plan has just been approved by the FCC, the agency will not automatically give carte blanche to similar plans in other states. The FCC has held that each case must be reviewed in a case-by-case basis to determine if this is the best way to bring equal access to the state. Norlight also faces challenges from the Wisconsin Public Service Commission on its network. The regulatory agencies have the power to either make or break the development of these niche markets.

3.5 FORECASTS

After a year of absolute frenzy, the fiber optic long distance market is beginning to show signs of settling down. In 1984 and 1985, during the long haul Big Bang, 24 companies had announced plans to initiate or expand their national and regional networks. By the end of 1985, the universe had begun to consolidate: some companies had consolidated, another had essentially dropped out, and others were seeking niches in secondary markets.

The reason for the slowing expansion was certainly not disenchantment with fiber optics. Instead, as carriers scrambled for customers, it became clear that the multiplicity of networks was generating overcapacity. And with evolving technology promising even greater transmission capacities, the situation could only get worse. As a result, the industry is in the throes of a shake-out.

It is extremely unlikely that there will be another period of such intense growth between now and the end of the millenium. To that extent, any "optimistic" forecast based on limitless expansion in the number or variety of networks is unfounded.

Similarly, it is unrealistic to expect that the universe will collapse back to its former state, with AT&T's gravitational pull sucking the other networks into its black hole.

The most likely scenario will be a continuation of present trends -- mergers, sharing of capacity, and the targeting of opportunities by smaller regional networks. Exhibit 3.7 presents a likely forecast of corporate activities. Expansion will continue to be incremental, with fiber optic spurs and connections being made as demand warrants. Although the industry will never reach a steady-state, it will not be as explosive as it has been over the past two years.

SECTION 4.0
FIBER OPTIC LONG HAUL NETWORKS

This section provides details on the development, configuration, services, suppliers, and strategies of all of the national and regional fiber optic networks.

4.1 NATIONAL NETWORKS

4.1.1 ALC Communications Corporation

Formed on December 19, 1985, ALC Communications is the product of the merger of Allnet Communications Services, Inc. and Lexitel Corporation. Under the agreement, Allnet and Lexitel will operate as a single company, Allnet Communications Services, which will be a wholly-owned subsidiary of ALC. With revenues of \$500 million and a customer base of nearly 500,000, ALC will be the third largest long distance carrier in the United States, representing about 1.5 percent of the long distance market.

To avoid the large capital required to build its own network, ALC plans to chiefly lease capacity from fiber optic networks. Several long-term leases have already been signed: with Lightnet to connect ALC with New York, Philadelphia, Baltimore and Washington, DC; with Litel's 1700-mile network to link the company with the major cities in Ohio, Detroit and Chicago; and with LDX's 1600-mile network extending from St. Louis to the Mississippi Gulf. The most recent addition to the network is ALC's agreement to lease capacity from Mutual Signal's 404-mile fiber optic network in Michigan. Exhibit 4.1 illustrates ALC fiber optic and microwave systems.

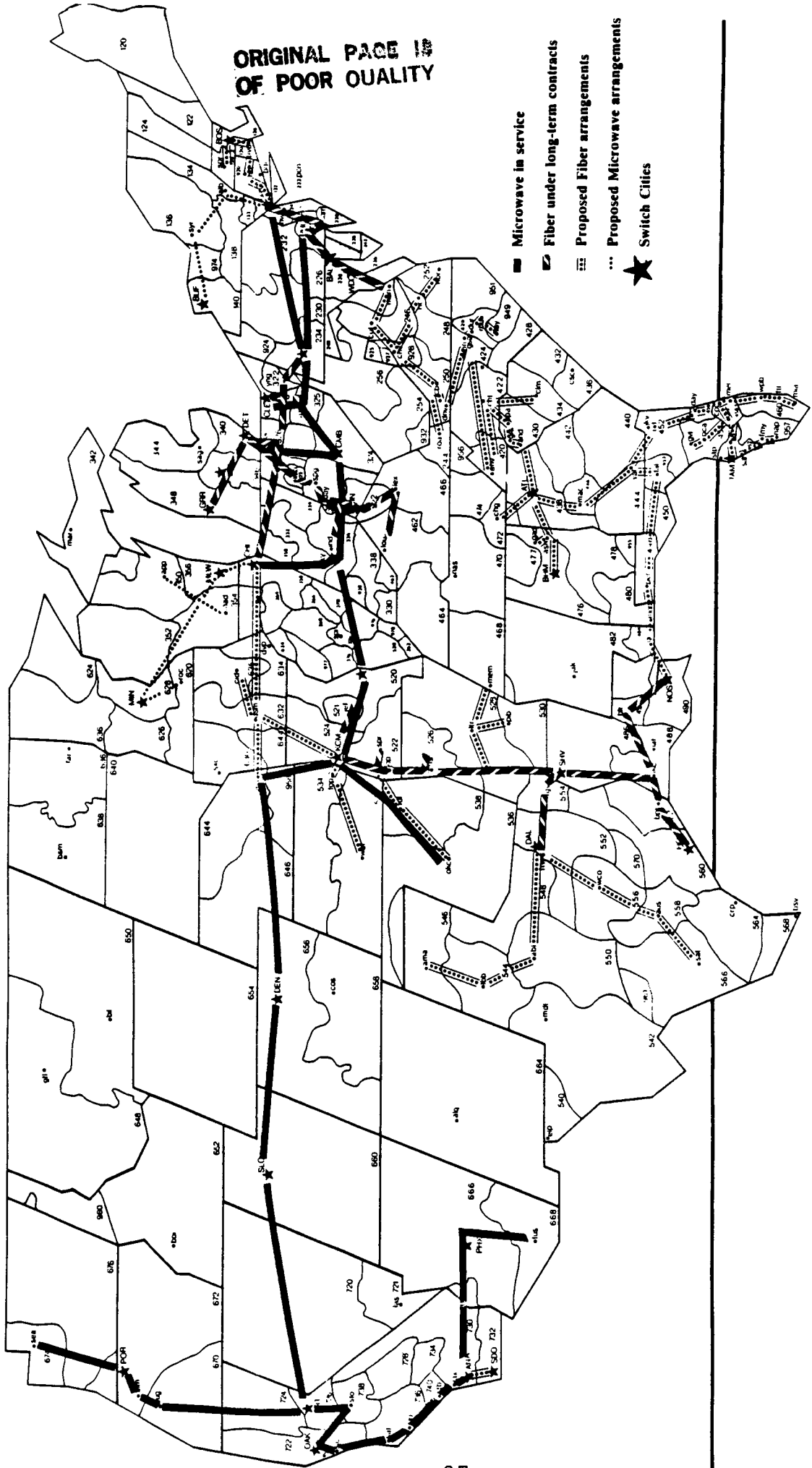
ALC offers both long distance and WATS service to homes and small-to-medium-sized businesses under the Allnet and MAX brand names. Though nationwide in scope, the company's marketing and sales strategies will focus on three regional areas of the United States: the Midwest, where the company has a relatively large share of the alternative long distance market; the western United States; and some areas in the Northeast. ALC plans to be a \$1 billion-plus company in three years and its growing fiber optic network will play an important role in reaching their goal.

4.1.2 American Telephone and Telegraph (AT&T)

The American Telephone and Telegraph Company (AT&T) is the largest long distance telecommunications carrier in the United States, providing a wide range of services and systems for the transmission of voice, data, and image.

EXHIBIT 4.1

Lexitel/Allnet Network



Historically, AT&T operated local and long distance facilities as a single nationwide network, sharing costs and revenues with local Bell Operating subsidiaries and independent telephone companies. As part of the consent decree signed in 1982, AT&T gave up its local Bell Operating companies and on January 1, 1984 reorganized into two main divisions: AT&T Technologies and AT&T Communications. AT&T long distance services, which fall under the latter division's domain, provides interstate switched long distance communications and forms the backbone transmission network for services provided by a number of other carriers and telephone resellers.

AT&T utilizes a mixture of transmission media for its long distance service, including coaxial and copper cables, microwave, satellites and fiber optics. To update its network, AT&T is transforming its analog network into a digital one. By the end of the decade, AT&T's digital network will encompass 35,000 miles and three domestic satellites. An important part of this strategy is the use to fiber optics.

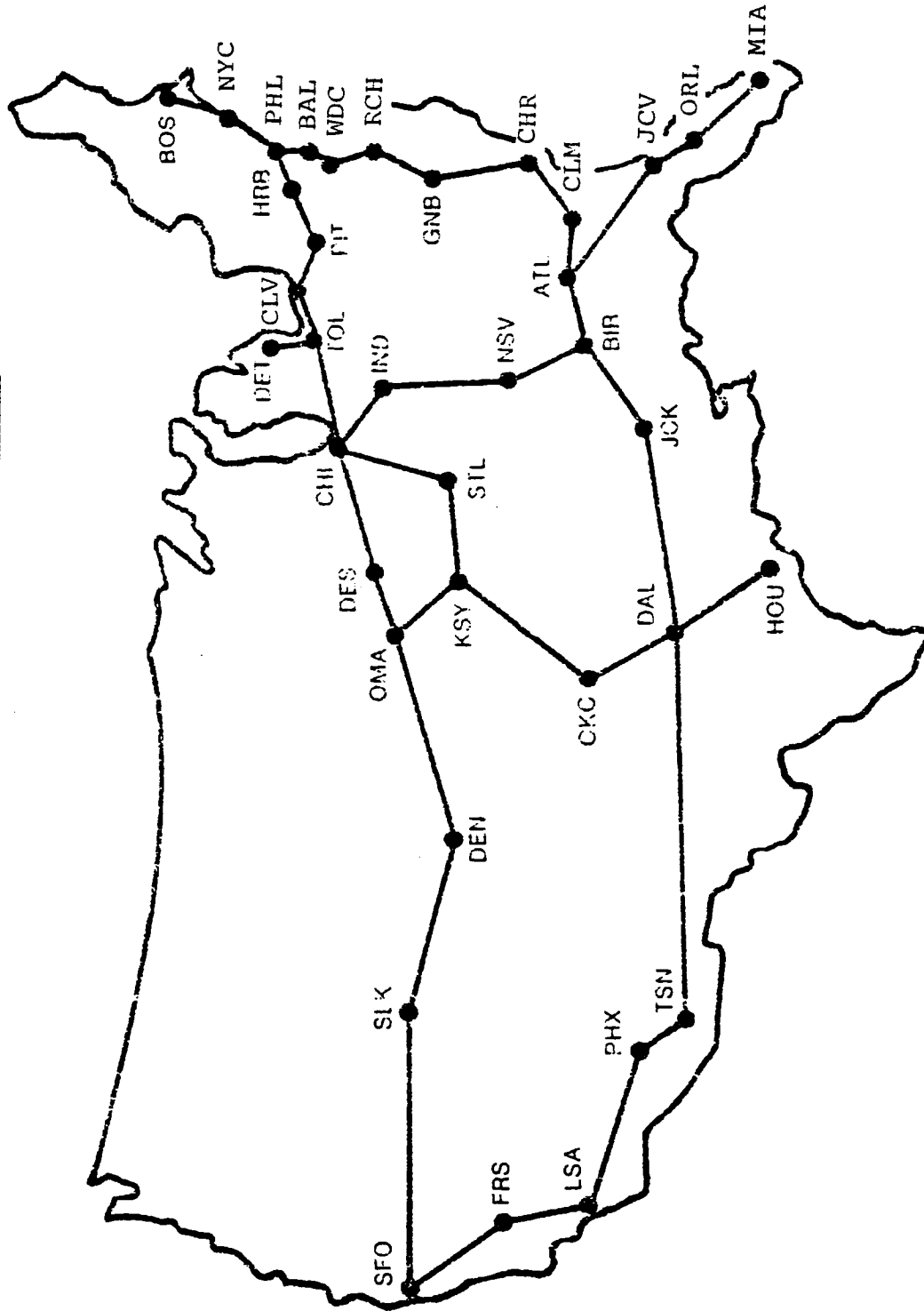
When designed in 1982, AT&T originally scheduled its long haul fiber optic network, with a scheduled 1995 completion date. The timetable and network design were both modified in November 1984, to reflect the carrier's efforts to accelerate the completion of its digital network to 1990. Exhibits 4.2 and 4.3 show the original and redesigned lightwave networks. AT&T's fiber optic system measures approximately 10,000 route miles.

AT&T was the first carrier to implement fiber optics into its long haul network, starting on both coasts in early 1983. February 1983 saw the first use of the Washington-to-New York portion of the Northeast Corridor project. This 372-mile link is part of the 775-mile system which begins in Moseley, VA and extends to Cambridge, MA (Exhibit 4.4). The New York-to-Boston half was put into service in 1984. West Coast service quickly followed. In March 1983, AT&T initiated service on 514 miles of the Pacific Corridor project, the first link in the system that extends north from San Diego to Sacramento. A branch connects the San Francisco-Oakland-San Jose loop to the main corridor line (Exhibit 4.5).

AT&T reports that the installation of its fiber optic network is proceeding according to schedule. Company sources report the entire network would be completed by early 1987. Leased rights-of-way have been secured from several railroads, including: Conrail, Florida East Coast Railroad, Union Pacific Railroad, CSX Corporation, Boston & Maine Railroad, Amtrak, and Grand Trunk Railroad. The cable is buried 42 inches, spliced approximately every 1000 feet, and the signal is strengthened approximately every 24 miles.

EXHIBIT 4.2

AT&T LIGHTWAVE NETWORK PLAN, 1982



Deployment Rate:
300,000 Cabled km/yr

22

EXHIBIT 4.3

AT&T DOMESTIC DIGITAL NETWORK -- 1990

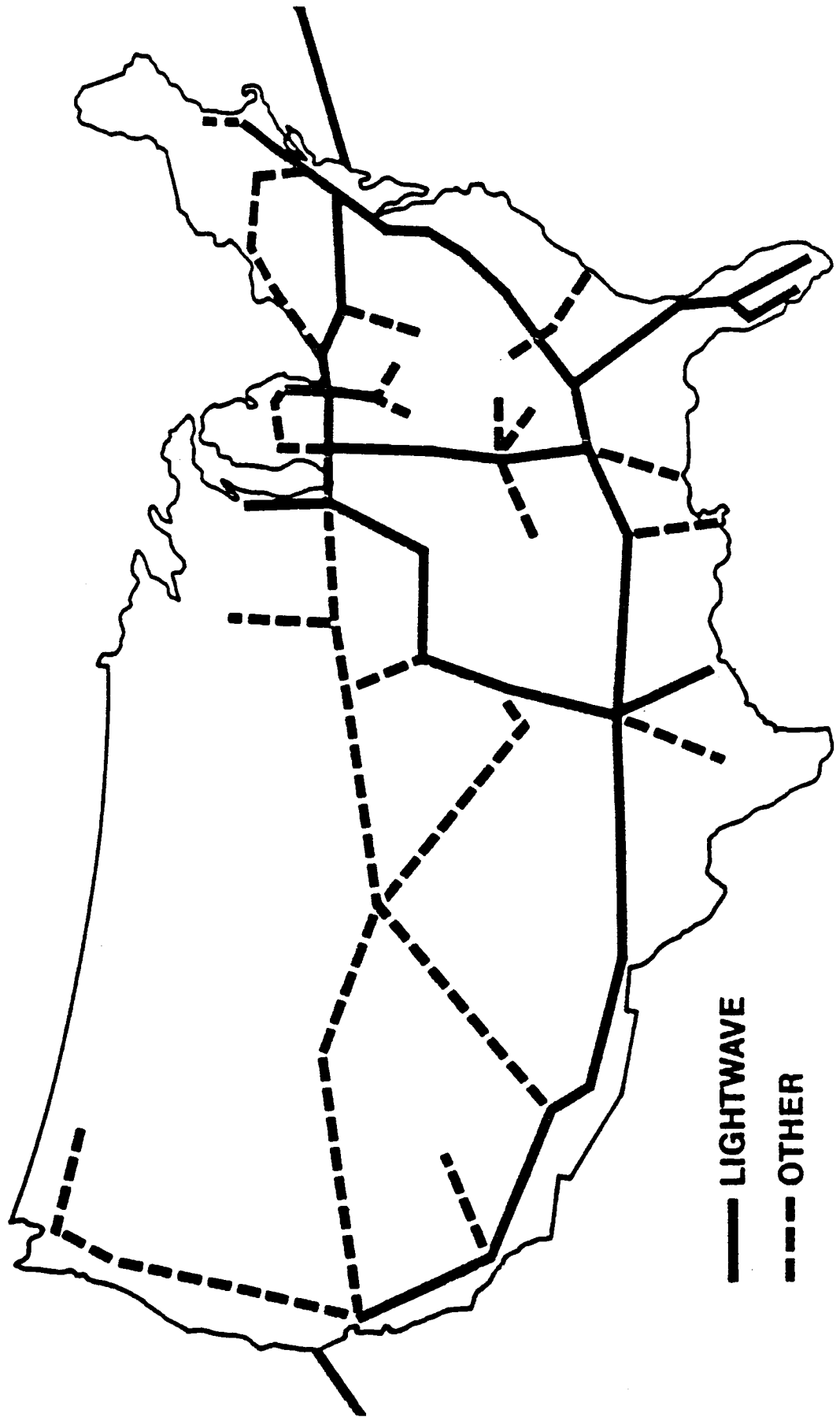
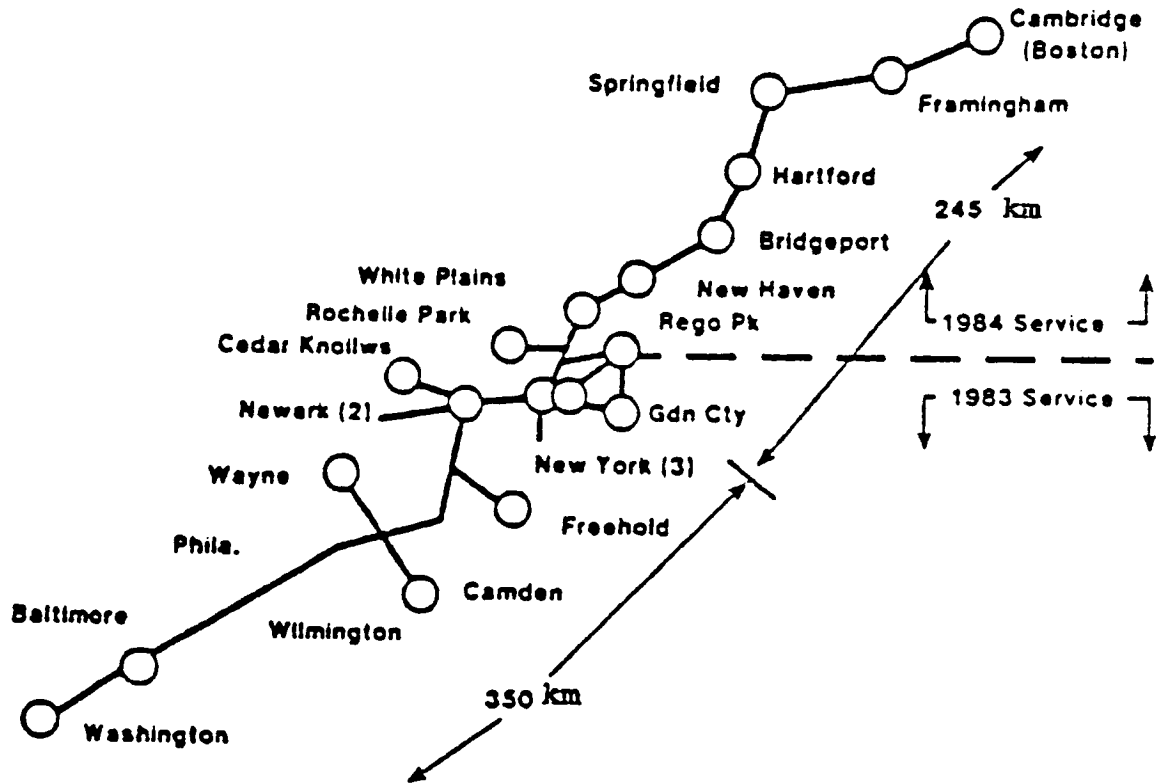


EXHIBIT 4.4

FT3C LIGHTWAVE SYSTEM NORTHEAST CORRIDOR



THE PACIFIC CORRIDOR PROJECT



AT&T Technologies is obviously a major supplier for the its lightwave system. A system of this magnitude, however, has forced even AT&T to seek alternative equipment sources; Philips CSD, Rockwell-Collins, Telco Systems, and NEC America have all provided electronics for its lightwave system.

To remain current with the latest technological advances in fiber optics, AT&T has continually upgraded its system. Multimode fibers were originally used by the network and repeaters were placed every four miles. As single-mode fibers have demonstrated their superior long haul transmission capabilities, AT&T has upgraded its system. For example, the carrier's first fiber optic segment from Cambridge, MA to Mosley, VA, has been entirely replaced with single-mode fibers. The transmission system is also being upgraded from 825 nm to 1300 nm.

4.1.3 Fibertrak

On July 25, 1985, Fibertrak announced that it would delay indefinitely delay construction of its \$1 billion, 7300-mile network. Although no longer a viable network, its inclusion here is useful as an example of the shake-out in the long distance fiber optic market.

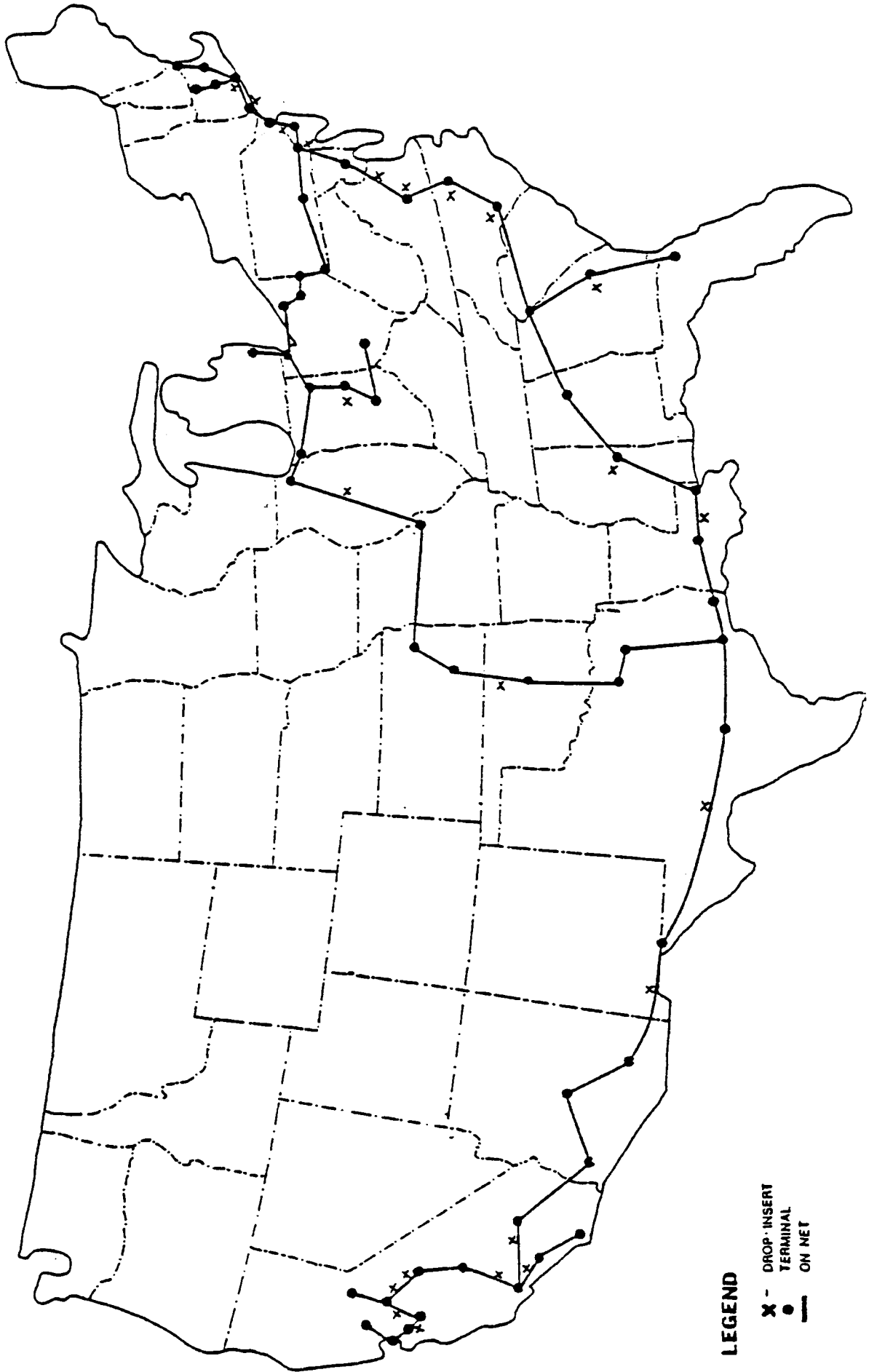
Fibertrak is a joint venture of two prominent railroads -- the Santa Fe Southern Pacific Corp. and Norfolk Southern Corp. -- which decided to cash in on their right-of-ways and to build their own network.

Exhibit 4.6 illustrates Fibertrak's proposed route. The proposed 12,000-kilometer network will connect California to the East Coast. Although the railroads have a combined right-of-way of over 40,000 miles, they do not own right-of-ways required to connect New York City. An agreement signed at the end of 1984, for 525 miles of Amtrak right-of-way, has given Fibertrak access to New York, Philadelphia and Washington, DC. The network, which should reach 80 percent of the U.S. population, was to be completed by 1987.

Each single-mode fiber cable would have contained 48 fiber pairs. Eight hundred repeater stations and 71 terminals located in the major metropolitan areas of the country are also included in the network's layout. Morris-Knudsen/Northern Telecom was contracted to complete the planning, pre-engineering and preconstruction work, and Bechtel Corp. was signed to complete the environmental impact studies required for its proposed nationwide network. No equipment contracts had been announced.

EXHIBIT 4.6

PROPOSED FIBERTRAK SYSTEM



LEGEND

- X - DROP-INSERT
- - TERMINAL ON NET
- ON NET

Fibertrak's targeted customers were carriers. Operating at 565 Mbps, customers would have been able to utilize the system in increments of 45 Mbps. Casting an eye toward the future, Fibertrak's design allowed for the eventual upgrading of transmission to 1.2 Gbps. Services to be provided included T1, T2, T3 and 64 Kbps data and digital voice circuits.

To entice companies to sign with Fibertrak before the system was constructed, the consortium offered potential clients founders' agreements. Fiber pairs leased under this ten-year, non-cancellable agreement were guaranteed the lowest available prices and that their annual price would rise less than four percent. At least one reseller, Fibernet, chose this system over other long haul networks due to Fibertrak's attractive prices.

Several factors have been attributed to Fibertrak's problems:

- Timing: The basis of Fibertrak is plausible, but the window of opportunity for building the system may have passed. Competitors like AT&T, U.S. Sprint and NTN have already cut over a significant portion of their networks while Fibertrak has not even begun construction. Even the need for Fibertrak's capacity in the wake of its competitors can be questioned. The long-haul fiber optic industry is in a stage of consolidation (as evidenced by recent mergers and the formation of the NTN consortium) and it is highly improbable that another competitor can be supported.
- Lack of Customers: Fibertrak's construction problems also hampered efforts to sign up customers. Usually companies want to utilize capacity with a system that is already or about to be operational; thus the first competitor in the area offering service has a distinct advantage in attracting business. Besides playing catch-up, Fibertrak will also have to win potential clients' confidence regarding the company's longevity. Customers want to utilize capacity from a system they know will be operational in the long term and Fibertrak's current problems do not promote such confidence.
- Financial Problems: When the number of signed customers did not reach expected levels, Fibertrak's resources were reportedly strained. Clients allegedly were required to provide up-front money to minimize Fibertrak's financial risk. Their financial planning may have compounded these problems. Expenditures were set at a high constant level instead of investing in increments matched by revenue levels.

While it may be premature to write Fibertrak's obituary, the consortium will have to resolve several serious problems if the venture is to proceed. Time is also against the project. The longer the construction is delayed, the greater the headstart of its competitors. As more systems are cutover, the probability of Fibertrak's revival grows dimmer.

4.1.4 MCI

MCI is the country's second largest long distance carrier, with an estimated 5 percent of the total long distance market. The company has invested heavily in fiber optics to augment its current analog and digital microwave and satellite transmission systems. Total network cost is estimated to run approximately \$600-\$700 million. When the fiber optic system is completed and connected to the terrestrial microwave system, MCI's total network will encompass 28,000 route miles, with 350 million miles of circuits.

Exhibit 4.7 illustrates MCI's entire nationwide network while the fiber optic portion of the system is outlined in Exhibit 4.8. MCI plans to concentrate its fiber optic network in areas of the country with the greatest communications traffic, e.g. east of the Mississippi River and along the California coast. Overall, the total fiber optic network will total approximately 7000 route miles.

Since the completion of its Washington D.C.-to-New York City link in May 1983, MCI has steadily cut over additional portions of its network. The 958 route mile Chicago to Washington D.C. link was completed in October 1985, and plans call for the entire eastern U.S. network to be operational by the end of 1986.

MCI laid its cable for the fiber optic network along several railroads' right-of-ways, including Amtrak, CSX, and Union Pacific Railroads. In total, MCI has the right to install cable on more than 7,300 route miles of railroad right-of-ways in the continental United States for its fiber optic network. In some cases, MCI has negotiated long term leases for the right-of-ways for a cash settlement, while in other agreements MCI will also provide the railroad with the use of fiber pairs for its own communications needs.

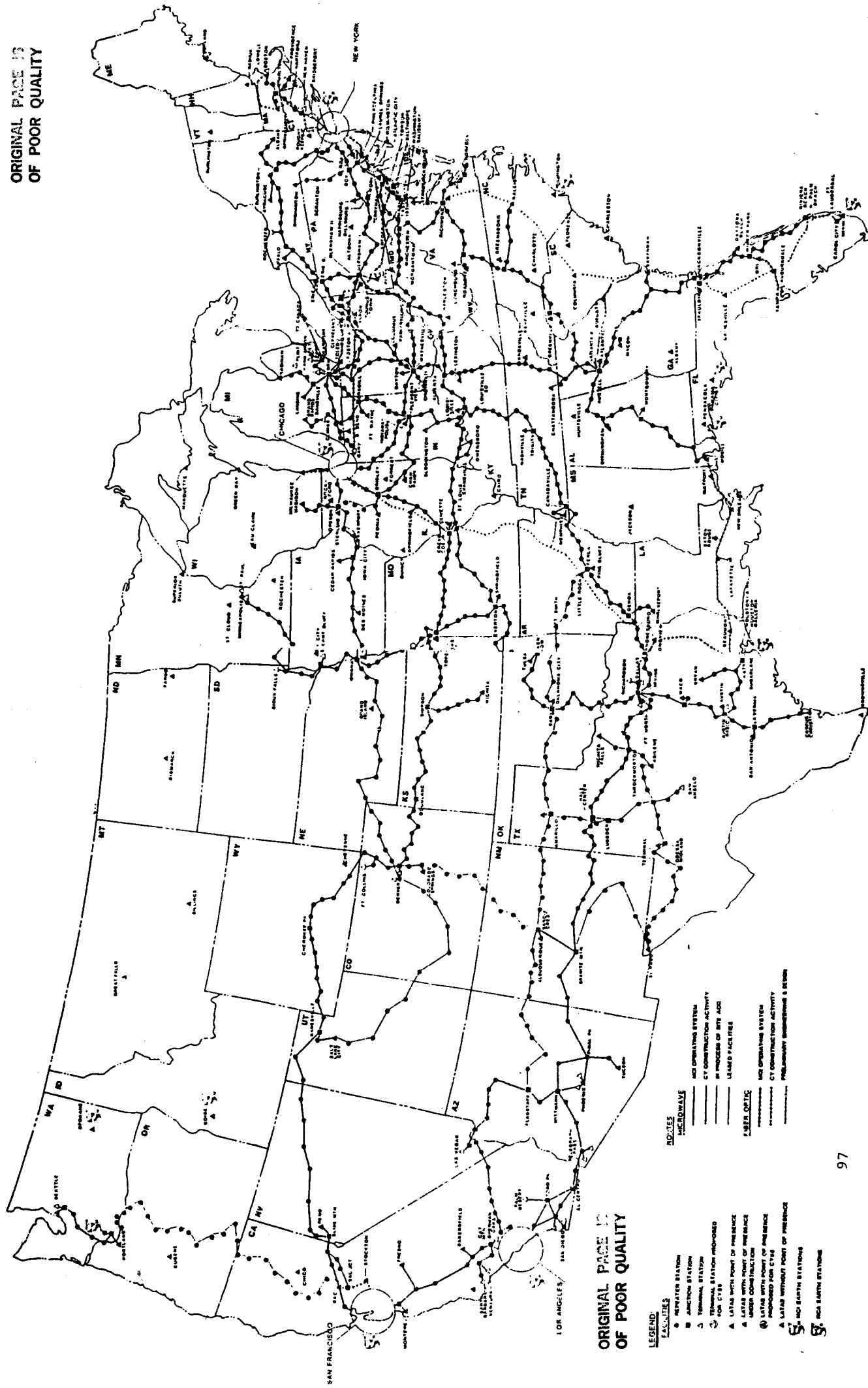
Cable is buried in the ground along the railroad, typically at a depth of three feet. Cables serving backbone routes contain 44 fibers, secondary routes contain 22 fibers, and minor spurs, depending upon traffic needs, may contain as few as six fibers. Repeaters are installed approximately every 20-25 miles.

FOLOUT FRAME

EXHIBIT 4.7: MCI'S NATIONWIDE NETWORK

FOLOUT FRAME

ORIGINAL PAGE IS
OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY

- LEGEND**
- FACILITIES**
- REPEATER STATION
 - JUNCTION STATION
 - TERMINAL STATION
 - TERMINAL STATION PROVIDED FOR CTSB
 - ▲ LATAS WITH POINT OF PRESENCE UNDER CONSTRUCTION
 - ⊗ LATAS WITH POINT OF PRESENCE PROVIDED FOR CTSB
 - ▲ LATAS WITHOUT POINT OF PRESENCE
 - ⊗ MCI SOUTH STATIONS
 - ⊗ MCI NORTH STATIONS
- ROUTES**
- MICROWAVE**
- MCI OPERATING SYSTEM
 - - - - - CT CONSTRUCTION ACTIVITY
 - · - · - - IN PROCESS OF SITE ACQ
 - LEASED FACILITIES
- FIBER OPTIC**
- MCI OPERATING SYSTEM
 - - - - - CT CONSTRUCTION ACTIVITY
 - · - · - - PRELIMINARY ENGINEERING & DESIGN

To fill geographic gaps in its long distance fiber optic network, MCI has begun to negotiate joint ventures with other carriers. For example, Ohio Bell will install a fiber optic cable transmission route for MCI which will provide the carrier with additional long distance call transport capabilities for its Greater Cleveland customers. MCI has also leased a 14.5 mile cable from Indiana Bell. The cable runs through Indianapolis and New Palistine which will spur off of the main backbone.

MCI has primarily used two cable suppliers for its fiber optic network: Northern Telecom and Siecor. Corning Glass Works manufactured the fibers. Rockwell and Fujitsu, whose largest customer for their higher speed 405 Mbps system is MCI, are the network's electronics suppliers.

MCI pioneered the use of single-mode fibers in long distance applications. Despite the lack of substantial technical analysis at the time, MCI decided to use single-mode fiber at a time when even AT&T was using multimode fibers. MCI's progressive thinking also applies to the electronics of the system. Lasers now operate at 1300 nm and MCI plans to upgrade to 1550 nm when they become cost effective, possibly within two or three years.

MCI plans to continually upgrade its transmission speed and system capacity so that the company can continue to expand its customer base and telecommunications services. Currently transmission speed is 405 Mbps, but MCI plans to begin installing Fujitsu's new 810 Mbps system in the second quarter of 1986 and to upgrade to 1.2 Gbps or higher as the evolving systems becomes more cost effective. Currently, MCI offers long distance switched, private lines, and DS-3 services.

4.1.5 National Telecommunications Network (NTN)

The National Telecommunications Network is a consortium of regional fiber networks. Faced with competition from systems like AT&T or U.S. Sprint, these carriers decided to join forces and form their own national network. Members include:

- Consolidated Network, Inc., St. Louis, MO
- LDX Net, Inc., Chesterfield, MO
- LiTel Telecommunications Corp., Worthington, OH
- Microtel, Inc., Boca Raton, FL
- SouthernNet, Inc., Atlanta, GA
- Southland Fibernet, Pensacola, FL
- Williams Telecommunications Co., Cedar Rapids, IA

Each of these will be discussed individually in the section on regional networks.

While maintaining their regional fiber optic networks, members will interconnect at designated cities to provide their customers with national fiber optic service. NTN coordinates marketing, technical standards, rates and tariffs, and regulatory aspects of operating the system. Members contribute to the administration of the venture, but each company finances and builds its own regional network only as large as they can afford. New construction is announced only after the sponsoring network receives its funding. This section examines NTN operations as a whole and its individual members are presented in the regional carrier section of this study.

As of January 1986, the network comprises more than 10,800 route miles stretching throughout the U.S. The majority of NTN's route mileage is located east of the Mississippi. Exhibit 4.9 presents NTN's most recent route map.

Exhibit 4.10 presents a status report of the completed and operational miles of NTN's system. Since the establishment of the consortium in February 1985, 44 percent of the proposed system has been installed and one third is operational. NTN is moving quickly to cutover its system in order to offer the first on-line fiber optic service in its service area.

Another important aspect of NTN's construction process is the interconnection of the member systems. When interconnecting, each pair of NTN members terminate their fiber optic cable at the same point. The transmission capacity is then converted into electrical signals at DS-3 level, and the two systems are then patched together. Transferring the transmissions to electrical signals is easier than fusing cable as it allows systems operating at different speeds to be easily joined.

Several members have already interconnected. In January 1986, LDX Net and Consolidated Net joined systems in St. Louis while Microtel and Southland Fibernet merged their networks in Tallahassee. Williams Telecomm is scheduled to hook up with LDX Net in Kansas City in April and with Litel in Chicago during May. SouthernNet and Microtel will interconnect during July in Atlanta. When Washington, DC becomes operational in August, a fiber circle covering the eastern half of the United States will be formed. NTN hopes to complete its currently funded system in the first quarter of 1987. Future plans include a link between Seattle and San Diego and a leg between Washington, DC and Boston, but no definite routes or additional system alliances have been announced.

EXHIBIT 4.10
NATIONAL TELECOMMUNICATIONS NETWORK
STATUS REPORT

COMPANY	ROUTE MILES		%
	PLANNED	CUTOVER*	
Consolidated Net	730	300	41.1
LDX Net	2,200	1,600	72.7
Litel	1,600	675	42.2
Microtel	1,300	731	56.2
SouthernNet	1,500	331	22.1
Southland Fibernet	330	272	82.4
Wiltel	<u>3,500</u>	<u>214</u>	6.1
TOTAL	11,760	4,123	35%

* As of 2/28/86

Most members' systems currently operate at 405 Mbps but plan to eventually upgrade their transmission speed to 565 Mbps. NTN provides high-speed, high-capacity telecommunications services for data, voice, full-motion video, facsimile, videotext and other sophisticated transmissions on a continuous transcontinental scale. NTN's wide range of current and future services includes:

- A number of types of private lines, all separate voice/data speeds and configurations: DS-1, DS-2, DS-3 and VF;
- All geographical bands accessible through WATS;
- MTS Switched Service, providing low-speed dial-up, data, facsimile and slow-scan/freeze-frame video capabilities for business and residence telephone subscribers;

- Electrical messaging;
- Tenant services;
- Switching service;
- Virtual networking, allowing for configurations that meet the customer's requirements.

NTN members have recognized two simple facts regarding the long distance fiber optic market: it is extremely competitive and it will be especially hard for smaller carriers to carve out any substantial business. The NTN consortium addresses these problems. By pooling their limited resources and route mileage, members can compete on a more equal footing with the telecommunication giants. The network also offers the advantages of both regional and national coverage, frequently servicing cities bypassed by the major carriers and yet offering an extensive geographic range. Members are also scrambling to complete their networks with the belief that the first totally operational nationwide system will have a head start on the competition.

There are still hurdles to overcome. NTN lacks a presence in the vital Northeast corridor and the consortium must work to ensure that consistent technological and service standards are maintained throughout the network. Overall, NTN should help to improve the survival chances of its members who otherwise would probably face the prospect of being overwhelmed by its titanic competitors.

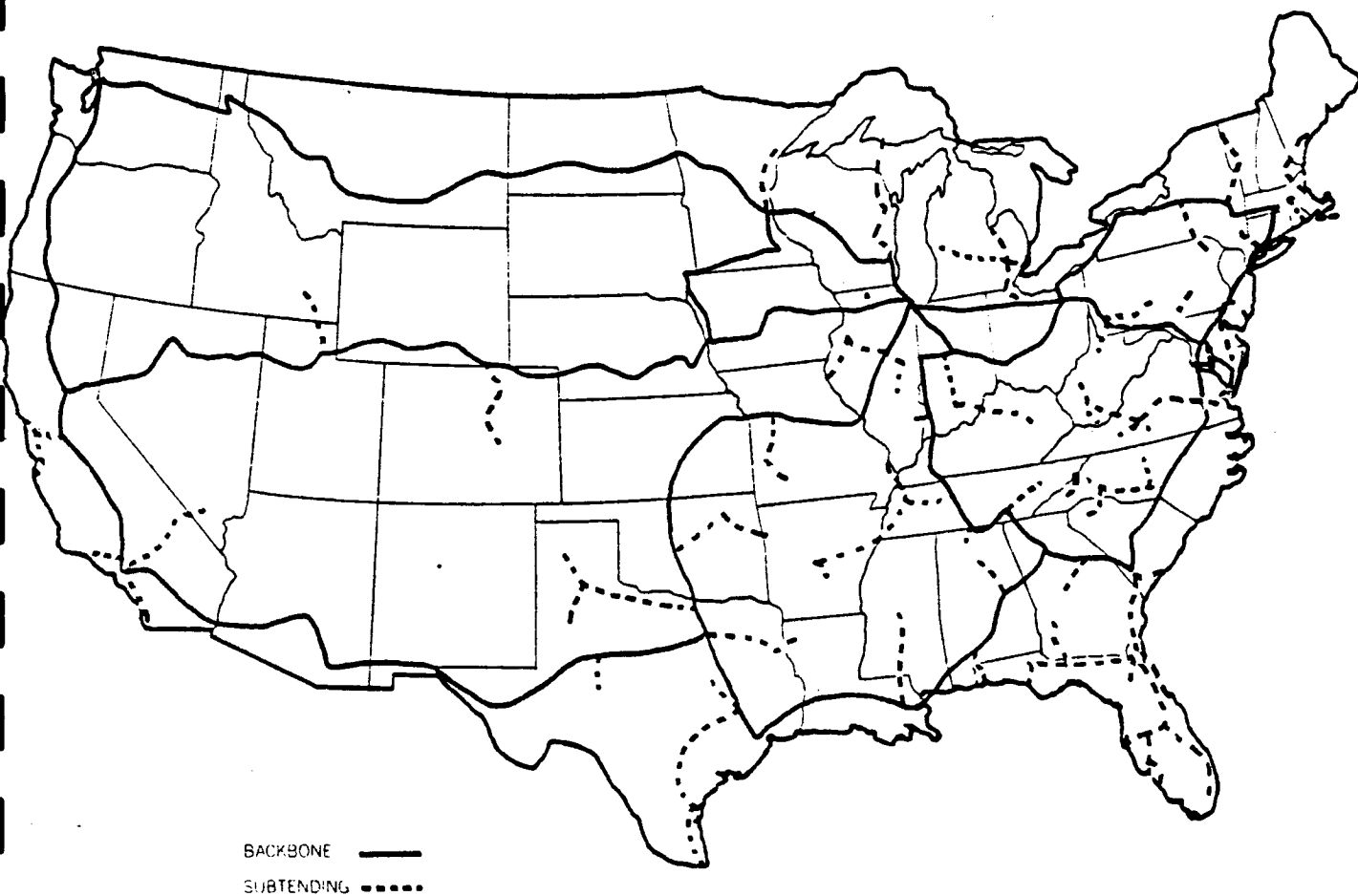
4.1.6 U.S. Sprint

U.S. Sprint is a product of the recent merger of GTE's and United Telecommunications's long distance and data subsidiaries. Announced on January 16, 1986, the merger combines the customer bases of the third and fourth largest carriers in the United States, totaling 2.2 million customers or approximately 4 percent of the long distance market.

The two companies hope to finalize the merger by mid-1986. One potential problem that may be encountered is the consent decree, signed when it acquired Sprint from Southern Pacific Railroad which limits GTE's future merger possibilities. However, as of March, 1986, little opposition to the merger has been voiced by the FCC or the Justice Department.

Originally, both companies had planned separate long haul fiber optic networks. Fortunately their combined routes are duplicated only in Florida. At the end of 1985, both companies had cut over a combined total of 6,200 miles: 4,700 by U.S. Telecom and 1,500 by GTE Sprint (Exhibit 4.11).

EXHIBIT 4.11



FIBER OPTIC NETWORK

U.S. Telecom's original network was more expansive, covering a projected 23,000 miles. The carrier plans to spend \$2 billion to construct the backbone and major subtending spurs and an additional \$2 billion from 1987-1990 to build its minor spurs. When completed, United Telecomm's route will interconnect every LATA in the United States. GTE Sprint's network was less extensive, with a total of 4000 planned route miles and a 1989 completion date.

U.S. Sprint's network is installed mostly along railroad right-of-ways. U.S Telecom negotiated agreements to use 18,000 miles of right-of-ways along 15 railroads.

Another significant step toward the completion of U.S. Sprint's fiber optic network is U.S. Telecom's agreement with Lightnet to purchase capacity along 3500 miles of Lightnet's routes in 21 eastern states. As part of the agreement, U.S. Telecom will build some of the routes under contract to Lightnet, including four branches which originate in Atlanta and connect to Washington D.C., New Orleans, Chicago, and Jacksonville. The carrier also received options to 5000 miles of right-of-ways to the CSX railroad for future subtending route construction.

By the end of 1985, several portions of U.S. Sprint's network was in place. The St. Louis-to-Chicago leg became functional in November of 1985. This mid-America backbone will eventually extend southward to Miami, northward to New York, and westward to Dallas/Forth Worth. The west coast portion will be finished by the end of 1986 and the Pacific Northwest by 1987.

Single-mode fiber will be used throughout the network. Repeaters are being placed approximately every 20 miles. In the city, the cables are placed in pipes. Depending upon the traffic requirements, cable size will vary from 6 to 32 fibers. The system's transmission speed is 565 Mbps. U.S. Sprint also plans to upgrade its system by installing AT&T Technologies FT Series G electronics, capable of operating at 1.7 Gbps, when it becomes available during 1986. Construction of a fiber optic network of this proportion requires 180 construction crews, working in 19 different states to install the system.

A network of this size also requires several vendors to provide all the required material. Cable suppliers include General Cable Company, Siecor, and Ericsson's Lightwave cable division. Ericsson is also the electronics supplier for the Chicago-to-Dallas route. Fujitsu and Stromberg Carlson will supply electronics on the other legs.

4.2 REGIONAL NETWORKS

4.2.1 Bandwidth Technologies, Inc.

In June 1985, Bandwidth Technologies announced plans to construct a fiber optic network serving the lower Michigan peninsula. A specially formed subsidiary, Optinet, Inc., will oversee the \$20.9 million network. The 300 route-mile network (Exhibit 4.12) links several Michigan cities, including Detroit, Grand Rapids, Lansing and Saginaw. Bandwidth plans to expand its current network with digital microwave, but no specific information has been released.

The carrier intends to construct and cutover its entire network in one year. The Detroit-to-Lansing leg became operational at the end of 1985. The two remaining segments to Grand Rapids and Saginaw will be completed by June 1986. The network is installed along the right-of-ways bought from the Consumers Power Company.

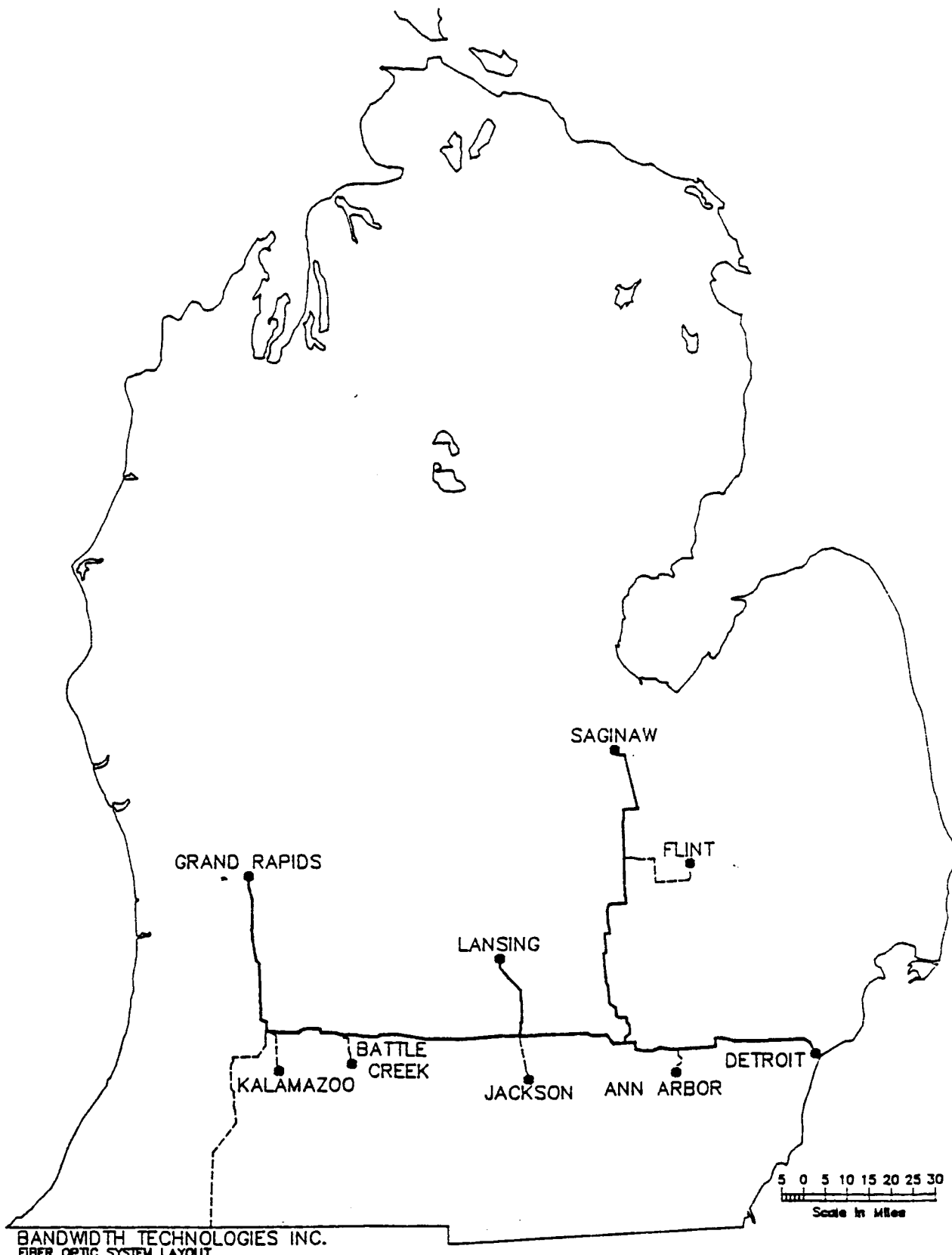
The Company contracted Morrison-Knudsen to build the network and Northern Telecom will supply the cable and electronics. Average fiber count for the system numbers eighteen with a transmission rate of 565 Mbps.

Bandwidth Technologies plans to target major common carriers (such as AT&T, U.S. Sprint and RCI) and communications intensive organizations as customers for their network. Its goal may be hard to meet. Mutual Signal, Walker Telecommunications' subsidiary, plans to construct a fiber optic network covering Bandwidth's route in addition to other Michigan cities. Besides being financed by large corporations like Walker and GE Credit Corporation, ALC Communications has already announced its intention to lease capacity on Mutual's system. Bandwidth has a significant advantage in that if its system is cutover on schedule, it will be the first operational system -- Mutual's entire system is planned to be cutover in September 1986. Bandwidth should use this lead time to the best possible advantage before the competition intensifies.

4.2.2 Consolidated Network, Inc.

Consolidated Net was formed early in 1985 as a subsidiary of Consolidated Communications, Inc., the holding company for the Illinois Consolidated Telephone Company. The subsidiary was established to complement Consolidated Communications' other services by providing long distance, inter-city telecommunications and special networking arrangements via a fiber optic network.

EXHIBIT 4.12



BANDWIDTH TECHNOLOGIES INC.
FIBER OPTIC SYSTEM LAYOUT

Consolidated Net primarily serves major cities in Illinois, with extensions to St. Louis and Indianapolis. The network measures 731 route miles (Exhibit 4.13). Consolidated Net also joined NTN in March, 1985 and plans to interconnect with fellow members in three cities: with LDX NET in St. Louis and with LiTel in Chicago and Indianapolis. Long term plans may even include a southern extension to Nashville.

Construction on Consolidated Net's system is partially completed. Over 300 route miles are operational including the main link from Indianapolis to St. Louis. The company is now connecting the remaining cities in its network, including Springfield, Bloomington, Champaign, Peoria, and Galesburg.

Northern Telecom is Consolidated Net's cable supplier. The cable, on average, contains 12 single-mode fibers. Consolidated Net is utilizing Rockwell-Collins electronics equipment in its system.

Operating at 565 Mbps, Consolidated Net offers customers DS-1, DS-3, and DDS services.

Consolidated Net is an example of a network which will serve primarily secondary markets, but which has attempted to enhance the marketability of its service by broadening its geographic range. The system brings fiber optic service to several cities in Illinois which have been bypassed by other major fiber optic carriers. This appeals to regional firms who may need Consolidated Net's services on a limited area basis. By linking with NTN, Consolidated Net also appeals to customers whose telecommunications needs may require a wider geographic area.

4.2.3 Digi-Net

Founded in 1984, Digi-Net Communications is a digital communications network serving four midwestern states. The \$65 million system will provide capacity to both commercial and carrier concerns.

Utilizing both microwave and fiber optics, Digi-Net's network will span 900 route miles and serve 48 major population areas including Chicago, Milwaukee, Dubuque and Minneapolis (Exhibit 4.14).

Cable is buried along the Chicago Northwestern Railroad right-of-way. To hasten system deployment of its link from Milwaukee to Minneapolis, digital microwave will be employed until its fiber optic system is cutover. The digital microwave will then be utilized elsewhere in the network once the fiber optic cable is operational.

EXHIBIT 4.13

CONSOLIDATED NETWORK

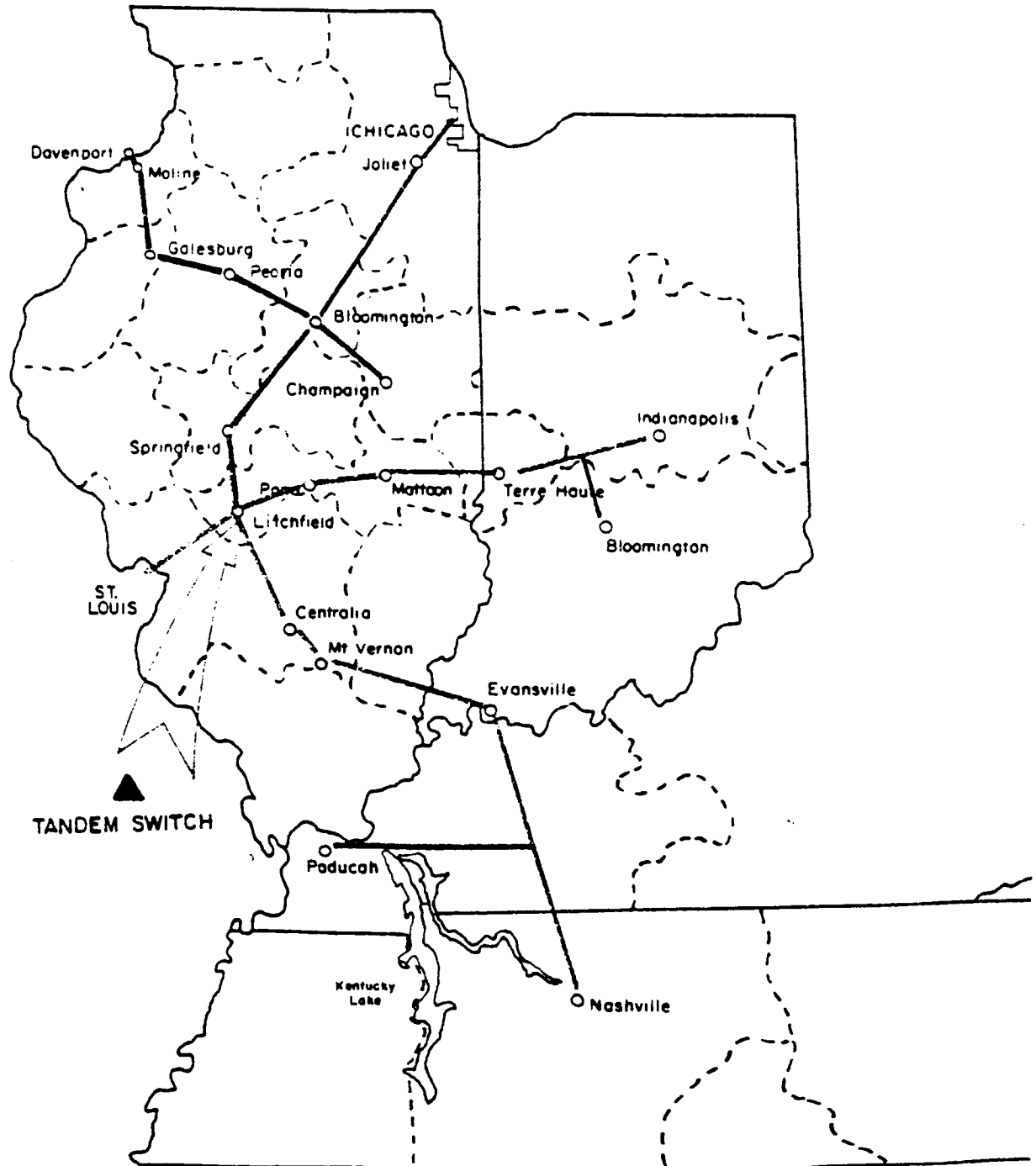
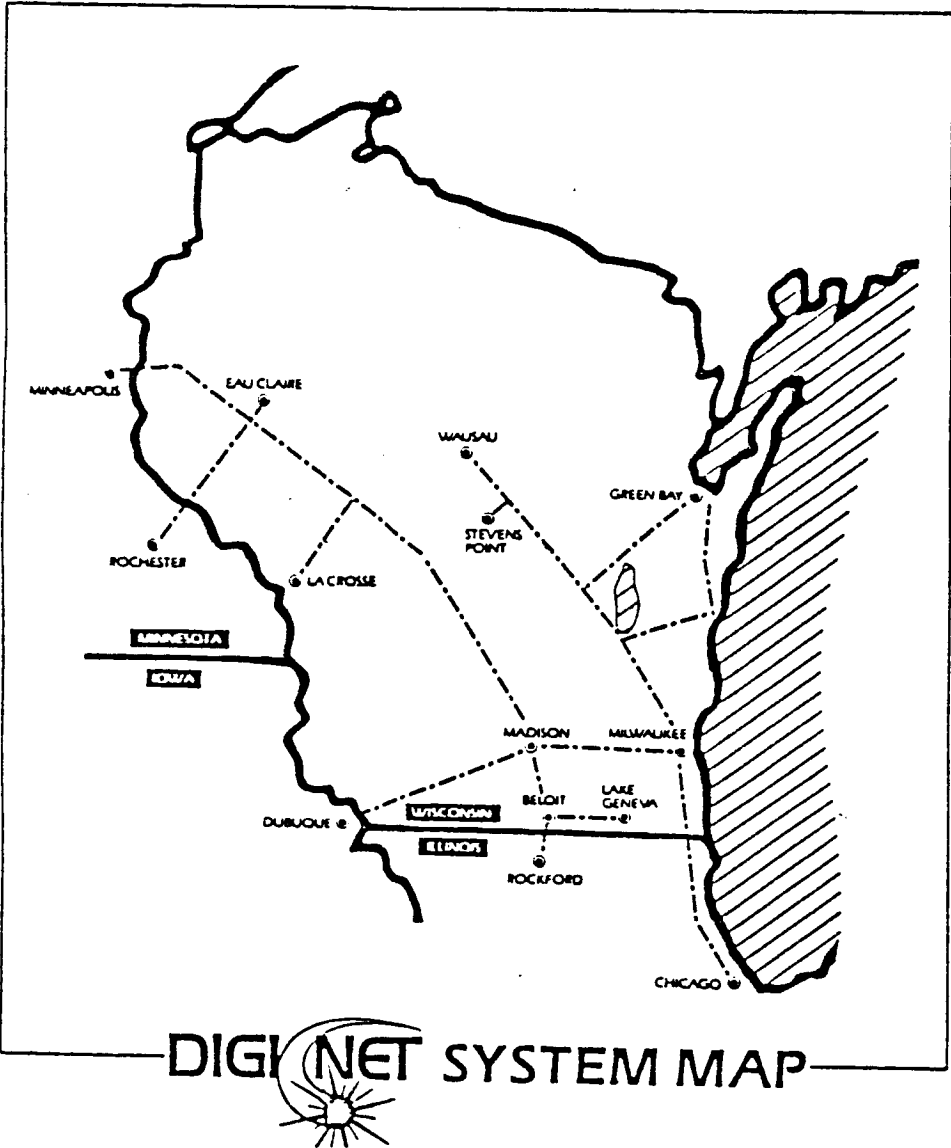


EXHIBIT 4.14



Digi-Net utilizes 32-fiber, single-mode cable operating at 1300 nm. Repeaters placed approximately every 15 miles support the Chicago-to-Milwaukee link of the system. Drop and insert capabilities are located in Racine, WI and Highland Park, IL. AT&T manufactured Digi-Net cable while Northern Telecom is the electronics supplier.

The carrier provides data, voice and video transmission. Interface is available at DS-0, DS-1, and DS-3 levels.

Digi-Net could be viewed as a connector system, linking the secondary cities of Wisconsin with the nearby major cities. Competition will not be keen since most cities were bypassed by the major fiber optic networks. It will be interesting to note whether there is enough communications traffic in the region to justify the bandwidth capability offered by Digi-Net's 32-fiber cable.

4.2.4 Electra Communications

Electra Communications is a joint venture between Cable and Wireless, PLC, London and the Missouri-Kansas-Texas Railroad (MKT). Incorporated in October 1983 to install and operate the network, MKT provided the necessary rights-of-way along its railroad track while Cable and Wireless designed and installed the \$50 million network.

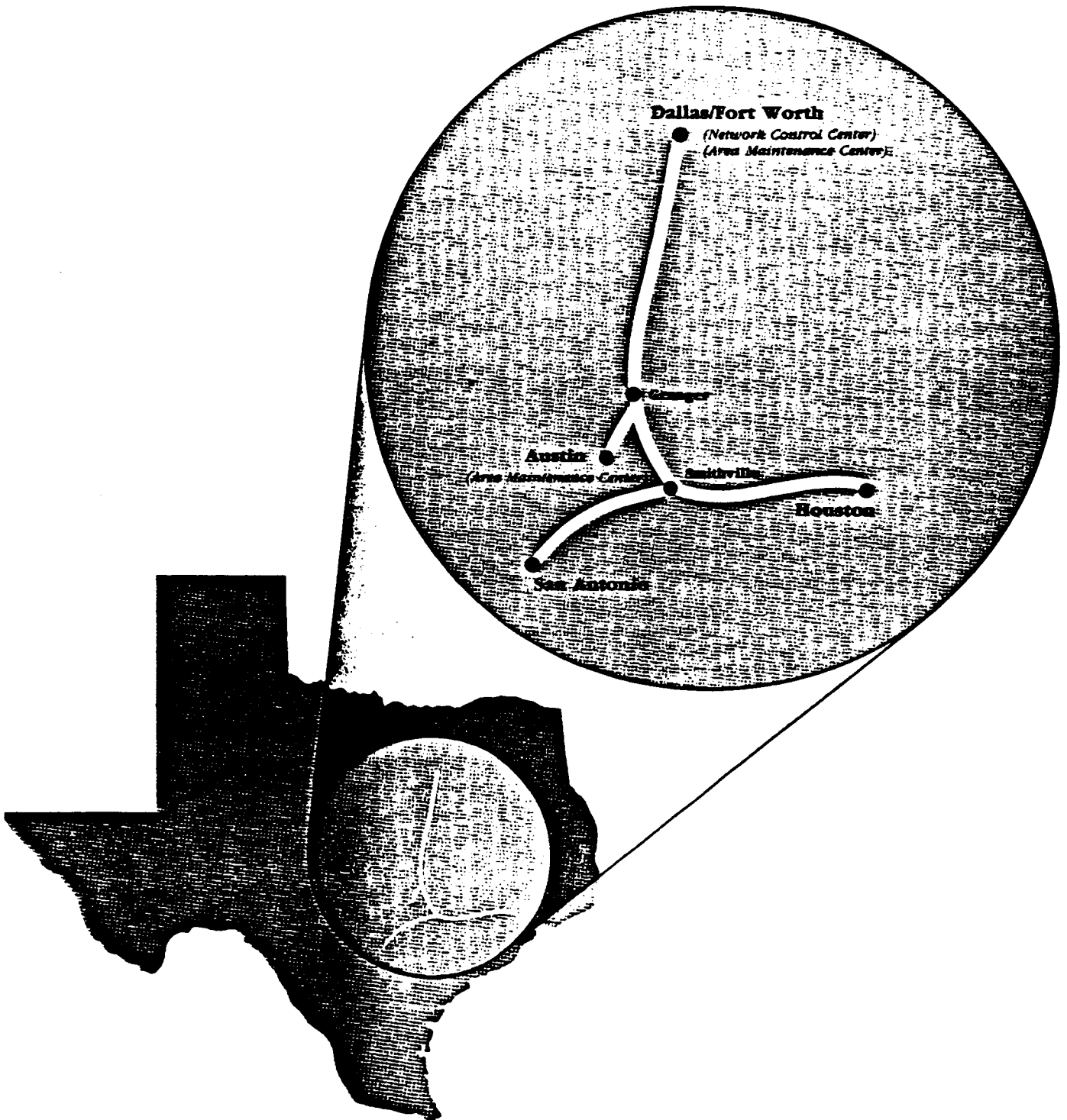
The 550-mile network serves four major cities in Texas: Dallas, Houston, Austin and San Antonio (Exhibit 4.15). The system design requires 19 repeater sites and three terminal nodes to be installed throughout the network. The entire system was cutover by the end of 1985.

To facilitate interconnection with local service, Electra offers its customers dedicated local fiber links in each city between its terminals and the Southwestern Bell Telephone Company central offices. Southwestern Bell is installing the fiber optic cable for local distribution of Electra's services while Electra will lease service. The twelve-year contract, valued at approximately \$12 million, could be expanded as the Electra system grows.

In the future, Electra plans to negotiate interface agreements with other similar regional fiber optic networks to commence inter-regional service. Its recent agreement with LDX Net to lease capacity from each other's networks represents their initial step toward meeting their expansion goals.

The Electra Network

TERMINAL LOCATIONS



Single-mode fiber operating at 1300 nm is utilized throughout the system. Different links of the system use varying cable sizes depending on anticipated traffic: 24 fibers between Dallas and Houston, 20 fibers between Smithville and Houston, and 16 fibers between Smithville and San Antonio. AT&T manufactured the cable for Electra's network. Placed in 1-1/4 inch plastic conduit, the cable is buried four feet beside the railroad track. The conduit permits an end-to-end path to be established prior to cable placement which reduces the number of cable splices and improves loss performance. AT&T's contract is worth approximately \$11 million: \$9 million for the fiber optic cable and \$2 million for splicing 571 miles of cable.

Other vendors include Fujitsu America, which provided the electronic transmission equipment, valued at \$7 million. DC power systems for all sites were designed and supplied by Telco Systems Fiber Optics Corp. Five Points Constructions installed the cable. Subcontracted by Five Points, Butler Telecommunications Service of Atlanta completed the route layout and other preliminary work (e.g. obtaining crossing permits).

The optical line transmission rate per fiber is 405 Mbps with an optical upgrade to Fujitsu's new 810 Mbps equipment. The network is designed to provide DS-3 channel for voice, data and video applications. Electra is aiming its service at large capacity users -- other carriers, government entities, Fortune companies and broadcast networks. The minimum unit of capacity available for lease is one DS-3 channel. Customers can then divide the channel to suit their needs.

Electra Communications is off to a promising start. Two customers have signed ten-year renewable leases. Pacnet Communications, Dallas has leased three DS-3 channels while Fiberline, San Antonio has chartered six DS-3 lines. Both companies plan to resell the transmission capacity to customers interested in leasing smaller units of capacity. The early completion of its regional network gives Electra an advantage in the marketplace and the carrier generally is the sole fiber optic system along most of its route. Not content to rest upon its laurels, Electra's agreement with LDX Net and its equipment upgrading plans leave the company well prepared for future growth.

4.2.5 Indiana Switch

Indiana Switch is a joint venture of U.S. Switch and a consortium of 27 independent telephone companies in Indiana, representing 70,490 access lines. The company has outlined two goals -- to produce equal access to local independent telcos through its Indiana Switch Access Division; and to provide switched long distance services through its Indiana Switch

Interchange. U.S. Switch provides the technical and organizational expertise required to aggregate the long distance traffic of the participating members at a single point so they collectively appear as a single market. The plan would require AT&T and other long distance carriers to use the switch and pay a fee to tap into the new system.

The proposal could have far reaching effects. The network will provide rural subscribers equal access to alternative carriers, thereby injecting long distance competition into secondary Indiana markets. It will also promote the efficient utilization of existing access facilities. System construction will soon begin now that the system has FCC approval.

Exhibit 4.16 illustrates Indiana Switch's proposed route. The 733-mile network comprises 683 route-miles of fiber optic cable supplemented with 50 route-miles of microwave to reach rural areas.

The backbone fiber optic link will connect Indianapolis, the central switch site, to Evansville and South Bend, with DS-3 drop and insert ports at Bloomington, Jasper, Kokomo, Logansport, and Plymouth. East from South Bend, digital radio will be used to reach Elkhart, and to the west, fiber will be used to connect to Gary/Chicago. Fiber will be extended northeast out of Indianapolis to Tipton, Huntington, and Fort Wayne.

At Bloomington, fiber will be buried to the west and terminate in Terre Haute. From Jasper west to Vincennes, digital radio will be used to interconnect with the fiber optic system. South of Bloomington, a fiber link will be extended from the backbone route to San Jacinto and New Albany/Louisville.

Access to the exchange carriers in the various cities will be via an access connection provided by the local carrier.

Indiana Switch plans to have the entire system operational within 18 months of FCC approval. The fiber optic cable will be buried in state road rights-of-way or purchased rights-of-way from private owners who are adjacent to the state roads.

A six to twenty-two single-mode fiber cable operating at 1300 nm will be used to connect the nodes of the network. The electronics will operate at 560 Mbps. Repeaters will be installed approximately every 25 miles. A tandem switch, located in Indianapolis, will provide the system's switching function. A 2 GHz digital microwave will be used to interface the fiber optic system in less densely populated areas.

EXHIBIT 4.16

Indiana Switch Route Map



Indiana Switch has allowed for future expansion. The system can be upgraded to 1500 nm and the optical electronics are expandable to double the current capacity. No suppliers have been announced yet though Indiana Switch estimates the system will cost \$23 million.

Indiana Switch represents a unique application of a fiber optic network. By uniting small telcos' long distance capabilities, their conversion to equal access will be faster and less expensive than previously planned. Interestingly, both AT&T and MCI fought the proposal, claiming the state switch organization will have unfair competition since they will provide both the switch as well as the long distance service. Countering these claims, Indiana Switch states it would charge itself the same rates for using the switch as it does the other long distance carriers. The proposal received FCC approval in mid-April 1986, and U.S. Switch now plans to expand this concept to other states.

4.2.6 Institutional Communications Company

Incorporated in November 1980, Institutional Communications Company (ICC) is a specialized carrier which plans to construct a 109-mile fiber optics system serving Washington, DC, Baltimore and their Virginia and Maryland suburbs (Exhibit 4.17). ICC will provide direct communications links to business, commercial and government agencies for dedicated networks and long distance switching, allowing them to bypass the local telephone company. While the FCC granted its license in 1983, ICC only recently completed the financial and right-of-way arrangements required to build the \$19.9 million network.

Construction started February 1, 1986 with a three-phase construction schedule:

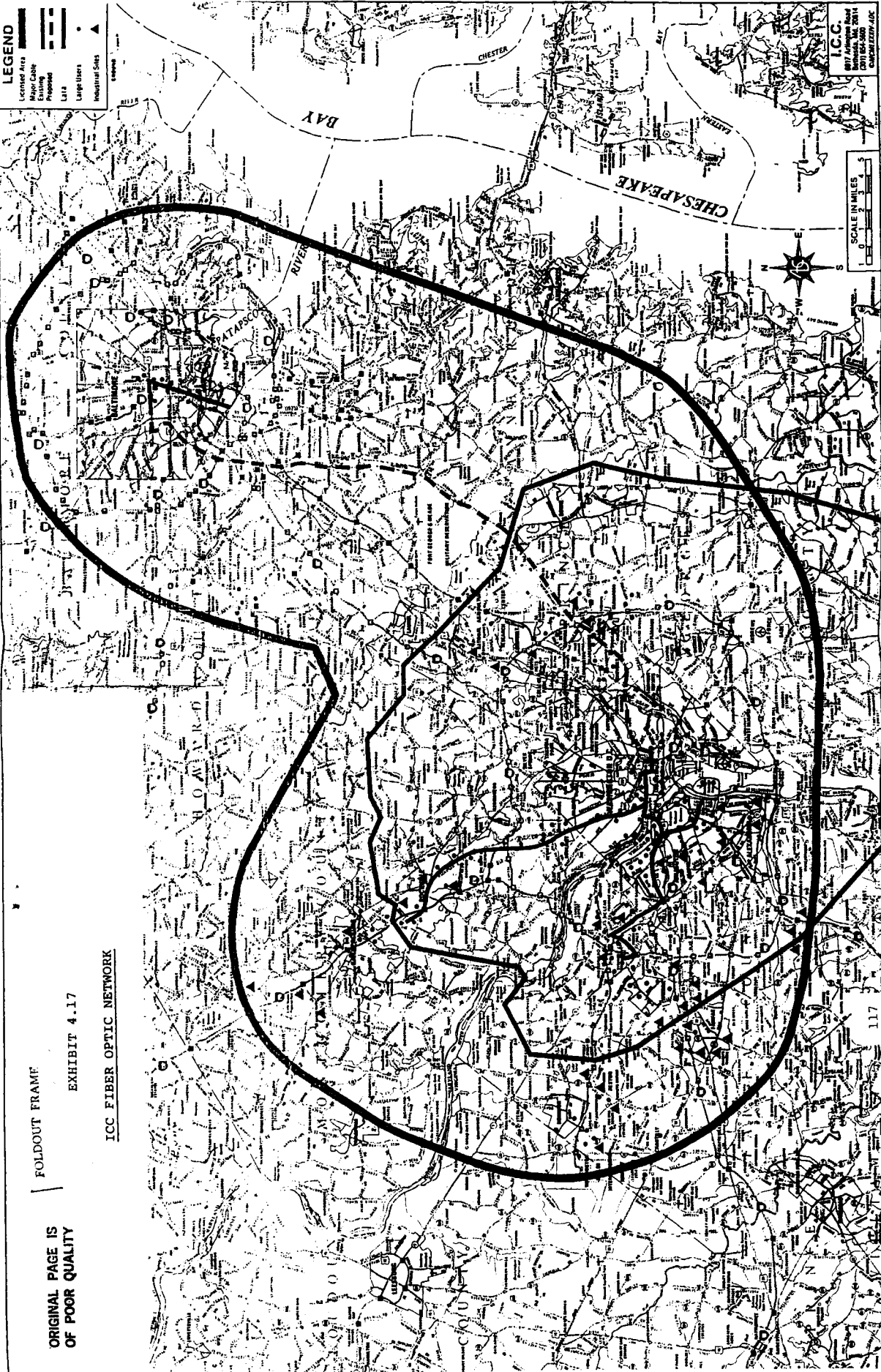
- Phase One includes the installation of fiber optic cable and the electronics for dedicated services on DS-1/2, DS-1 and DS-3 to be completed during the second quarter of 1986;
- Phase Two includes full electronic switching capabilities with completion due during the third quarter of 1986; and
- Phase Three includes the cutover of the Baltimore link and expansion of services to be completed by the end of 1986.

The cable will be placed in existing underground ducts or strung along utility poles. The Washington, DC-Baltimore link will be leased from owners of existing fiber optic cables.

FOLDOUT FRAME

LEGEND

- Licensed Area
- Major Cable
- Existing
- Proposed
- L17
- Large Users
- ▲ Industrial Sites
- Service



FOLDOUT FRAME

EXHIBIT 4.17

ICC FIBER OPTIC NETWORK

ORIGINAL PAGE IS
OF POOR QUALITY

SCALE IN MILES
0 1 2 3 4 5

ICC
877 American Road
Baltimore, MD 21286
GANNETT-ZENY, INC.

The network is designed with a main switching system in Baltimore and Washington to provide switched service from ICC customer locations to long distance carriers or within the ICC system. The system will have connectors to those major customers who have contracted for service prior to the start of construction. Additional connections to future customers will be engineered on an as-required basis. Morrison-Knudsen Technologies, Inc. will build the entire system.

Each fiber pair will operate initially at 140 Mbps and will gradually be upgraded to 565 Mbps as demand increases. The fiber optic transmission system will provide inter-switch trunking on a T-1 basis from three remote switch locations (Baltimore, Rockville, Tysons Corner) and the four OCCs (AT&T, GTE, MCI, SBS) to the Washington office.

The network will be engineered to interface with customers on a T-1/2, T-1, T-3 or broadcast quality television signal basis. Both switch and unswitched/dedicated service are offered.

ICC has a large pool of potential clients from which to draw -- the many government agencies and large companies in the Washington, DC area. The service could help many clients to save considerable capital outlays by providing them with ready-made facilities in which to create their own dedicated systems and to connect with long distance services.

4.2.7 LDX Net

LDX Net, a member of NTN, is constructing and operating a \$110 million fiber optic network serving the mid-Southwest. Incorporated in May 1984, LDX Net has capitalized on the resources of its parent company, LDX Group. These resources include the communications right-of-way along the Kansas City Southern Railroad, provided by LDX Group's majority shareholder, Kansas City Southern Industries, Inc.

The LDX Net network includes 2200 route-miles linking the major cities in Texas, Louisiana, Oklahoma, Missouri and Kansas. Exhibit 4.18 presents the LDX Net system.

Construction of the network started in October 1984. Progress has been steady and almost 1000 miles have been cutover. Rights-of-way along the Union Pacific and Kansas City Southern Railroads, highways and pipelines have all been utilized.

In addition to building its own system, LDX Net has leased capacity and equipment from other telephone companies as an alternative to building its own system. For example, LDX has signed an eighteen-year, \$9 million contract to use Southwestern Bell Telephone Company's local network in three cities to

EXHIBIT 4.18



originate and terminate calls on its long-haul fiber network. LDX will use Southwestern Bell's fiber optic facilities in Houston, Dallas and Beaumont, Texas to carry traffic from a central office to the LDX interexchange network. LDX will pay Southwestern Bell \$500,000 annually to use its facilities. In addition, South Central Bell is leasing LDX Net a total of 30 miles of fiber optic cable to be used in the New Orleans and Baton Rouge portions of its fiber optic network. The seventeen-year lease is valued at \$5 million. LDX Net has also negotiated with Electra Communications to extend its network to San Antonio and Austin, utilizing Electra's facilities.

The entire system is scheduled for completion in the second quarter of 1986.

The network, like most long-haul fiber optic networks, will utilize single-mode optical fiber cable and 565 Mbps transmission electronics. LDX Net has used several suppliers to install its systems. Cable suppliers include Ericsson, AT&T Technologies, Pirelli, and Siecor. Fujitsu and Ericsson are electronics suppliers.

LDX Net is the first company to utilize dispersion shifted fiber which will be installed in the Kansas City to Joplin, MO link of its system. To encourage the use of this new type of cable, Ericsson Lightwave constructed a hybrid cable containing 24 fibers -- 12 with regular single-mode fiber and the remaining with dispersion shifted fiber. LDX Net agreed to install the hybrid cable figuring this would be the most flexible method to upgrade the system in the future. The hybrid cable gives LDX Net the option of operating initially at 1300 nm on the regular single-mode fiber and eventually upgrading to 1550 nm on the dispersion shifted fibers when traffic increases.

All LDX Net service offerings provide full-time, point-to-point communications for voice, data, video or other applications. Standard service offerings include VF, DS-1, DS-2, and DS-3.

LDX Net has constructed its fiber optic network shrewdly. Its use of specially designed hybrid cable will ease any future system upgrading. The system has saved considerable construction cost by leasing capacity from other systems, and its NTN membership further expands its service area. LDX has another advantage in that its network covers an area less crowded with fiber optic competitors than in other portions of the country.

4.2.8 Lightnet

Lightnet is the ambitious \$500 million project of Southern New England Telephone Company (SNET) and CSX Corporation, the nation's largest transportation and natural resource company. In

1983, the companies joined forces to build a fiber optic backbone network throughout the eastern half of the United States. CSX provides its 27,000 miles of railroad rights-of-way connecting major cities, and SNET is responsible for engineering, construction and operations activities. SNET and CSX formed subsidiaries -- Sonacor Fibercom and CSX Communications -- that own Lightnet.

The 5000-mile network links 43 cities in 24 states east of the Mississippi (Exhibit 4.19).

Construction of the Lightnet system has proceeded in four phases. The company reports installation is proceeding on schedule: the Florida link was cutover in January 1985. Lightnet plans to cutover the New York-Chicago segment during early 1986 while the end of 1986 is Lightnet's goal for the completion of the Atlanta branches which will be built by U.S. Telecom. The company is striving to complete the entire network by 1987.

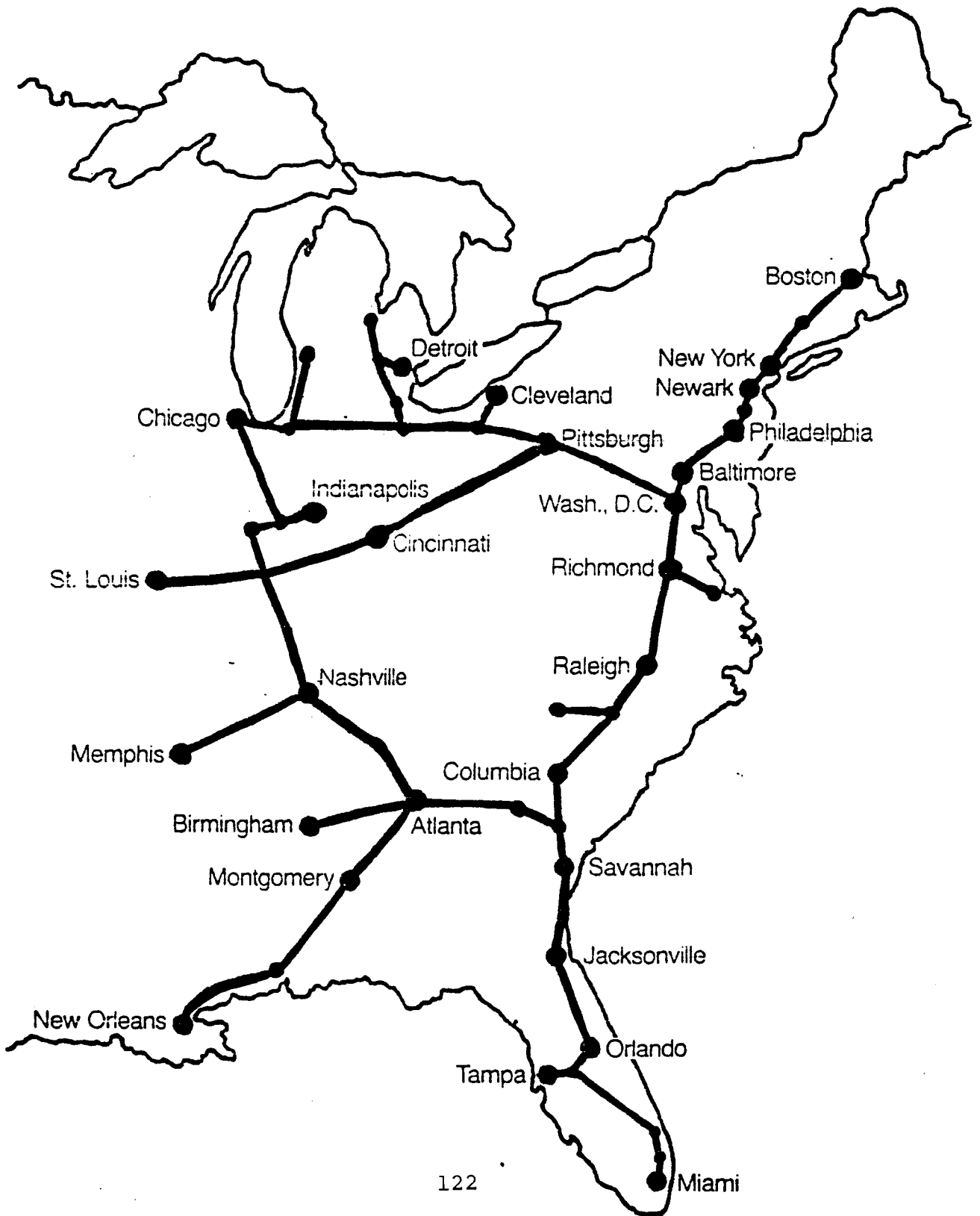
Utilizing CSX's land, the fiber cable is buried three feet deep along side the railroad track. Cables contain 38 to 48 single-mode fibers.

Repeaters are placed approximately 17 miles apart. At the regenerator locations, environmentally controlled vaults are used to store the electronics required for connection to the local power source. The system's centralized monitoring point is located in Atlanta. At each metropolitan area, there is a terminal with access to each customer's signals. Lightnet users must provide their own "last mile" connections for local distribution of the transmissions, though Lightnet's engineers will help users develop the most feasible means of interconnection.

AT&T Technologies is supplying the network's cable and electronics. Lightnet contracted both AT&T Network Systems and Ericsson Network Projects for splicing services. Several construction companies will install the system including Burnup and Sims, Byers Communications Systems, L.K. Comstock and Company, Henkels and McCoy, Michaels Pipe Line Construction, L.E. Myers Company and Pangborne Co. Lightnet has refused to announce the total cost of the system, but it is estimated to reach several hundred million dollars.

Initially, Lightnet uses 1300 nm lasers which operate at 90 or 180 Mbps. In 1986, Lightnet anticipates installing AT&T Technologies FT series G electronics in its system, which will operate at 417 Mbps and be upgradeable to 1.7 gigabits per second, the equivalent of 36 DS-3 signals.

LIGHTNET'S FIBER OPTIC NETWORK



Aimed at large users, Lightnet will sell capacity in blocks of 90 Mbps or more either through outright purchase or long-term leasing arrangements on a link-by-link basis. Customers access their signals at terminals along the route to use for voice and data transmissions or other needs.

Lightnet's marketing strategy is to convince potential customers to invest in an existing fiber optic network instead of building their own system. To stimulate sales, Lightnet has stressed its long-term commitment in the venture and encourages customers to do the same by purchasing its fiber optic lines. The company also stresses its flexibility to meet customer needs -- designing the best way to exit the network at various nodes and incrementally upgrading capacity as needs increase. The ownership opportunity is particularly attractive to large customers who want to control the development of their communications system now and in the future.

Lightnet has signed several major customers, including:

- U.S. Telecom (now part of U.S. Sprint) purchased capacity along 3500 miles of Lightnet's routes in 21 Eastern states. Additionally, the company has agreed to install the cable on the four branches originating in Atlanta. Rather than building a competing fiber optic network on the eastern United States, U.S. Sprint decided to utilize Lightnet's facilities which will be compatible to their own national system. The agreement is mutually beneficial -- the construction of U.S. Sprint's system is hastened while Lightnet's network is now compatible with U.S. Sprint's western links.
- Americall LDC, a reseller of long distance services to businesses and residences in Florida, plans to use Lightnet's Florida network. The fiber optic network allows Americall to expand its services to include high-speed data transmission, teleconferencing and video conferencing.
- Cable and Wireless of Great Britain has announced that it will purchase fiber optic transmission capacity on the Chicago-to-Washington, DC route, which should be operational in early 1986.
- RCI agreed to purchase capacity on Lightnet's system from New York to Washington, DC. Tentative discussion concerning the geographic extension of the agreement to points south of Washington and Chicago have also been held.

4.2.9 LiTel

LiTel, a privately-owned company, has secured major financing through private placements of stocks with companies in telecommunications-related fields, including Pirelli Cable, Alltel Corp, Centel Corporation, and Telettra. In addition, LiTel obtained a \$10.3 million loan guaranteed by the French government for the purchase of optronics and electronics from the Societe Anonyme de Telecommunications, the first time the French government guaranteed a loan to a start-up company. Total construction cost is estimated between \$77 million and \$85 million.

The LiTel network (Exhibit 4.20) includes a 1600-mile loop through seven states in the Midwest. Cities served include Chicago, Indianapolis, Cleveland, Cincinnati, Detroit, Akron, Youngstown, Toledo, Columbus, Southbend, Warren, Ft. Wayne, Dayton, Springfield, Lexington, Louisville, Pittsburgh, and Buffalo. As a member of NTN, LiTel plans to interconnect with its fellow members, Consolidated Network and Wiltel.

LiTel cut over most of its system by the end of 1985. Remaining cities are scheduled to be included by the first two quarters of 1986. Cable will be placed, depending upon right-of-way negotiations, either on telephone poles, in conduits, or buried underground. Right-of-ways from railroads, public utilities and the Ohio Turnpike Commission, which allowed LiTel to lay cable along 241 miles of toll road, will be used to lay cable.

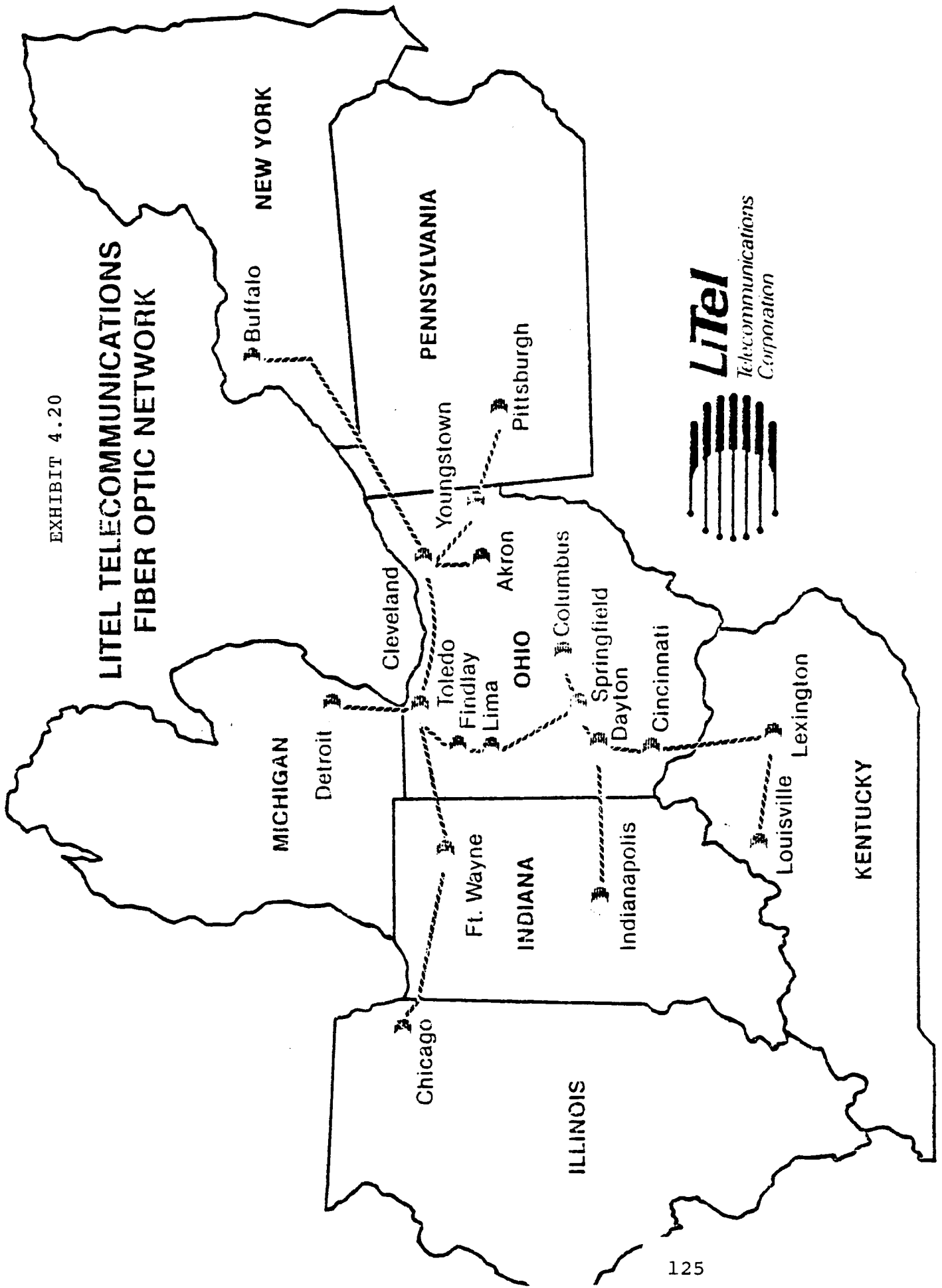
Pirelli, a major LiTel investor, supplied and installed the network's cable. On average, the cable contains 18 single-mode fiber strands. Electronics for the system are supplied by Northern Telecom and Societe Anonyme de Telecommunications.

Originally operating at 140 Mbps, LiTel's agreement with the French government allows them to upgrade their transmission speed to 565 Mbps. Several services are offered: standard interfaces including DS-1 and DS-3, WATS service, and private lines. The LiTel network, via three gateway switches, will have links to other common carriers.

LiTel's strategy was to presell their service before network installation, but this may prove to be a considerable challenge in the highly crowded market. One major challenge facing LiTel is signing up clients in an already saturated market. The company's deep pockets and premiere transmission should help to address this problem. Another advantage is their affiliation with NTN, which broadens LiTel's service coverage.

EXHIBIT 4.20

LITEL TELECOMMUNICATIONS FIBER OPTIC NETWORK



4.2.10 Microtel

Microtel, founded in 1981, is the owner and operator of the nation's first intrastate fiber optic network. The company compared three technologies -- microwave, satellites, and fiber optics -- for their planned network transmission medium, and based upon its analysis of technology and costs, decided to go with fiber optics. Dubbed LaserNet, the \$60 million network is owned by E.F. Hutton, Centel, and M/A-COM.

Originally designed to service only Florida, the network now comprises over 1300 route miles, extending through southeastern and central Georgia and terminating in Atlanta (Exhibit 4.21). In January 1985, Microtel joined NTN and plans to interconnect fellow members in both Atlanta and Tallahassee. Microtel finished construction of its Florida routes in 1985. The Georgia extension is targeted for completion by the end of 1986.

The Lasernet system utilizes both public road and railroad right-of-ways for cable installation. On four links -- Tampa to Cocoa, Tampa to Naples, Orlando to Gainesville, and Jacksonville to Pensacola -- all the cable is installed on public highway beds. The Miami-to-Atlanta route utilizes Florida East Coast Railroad's right-of-ways. Microtel estimates that the construction costs on the public roadbeds runs approximately five times higher than installing cable on railroad right-of-ways.

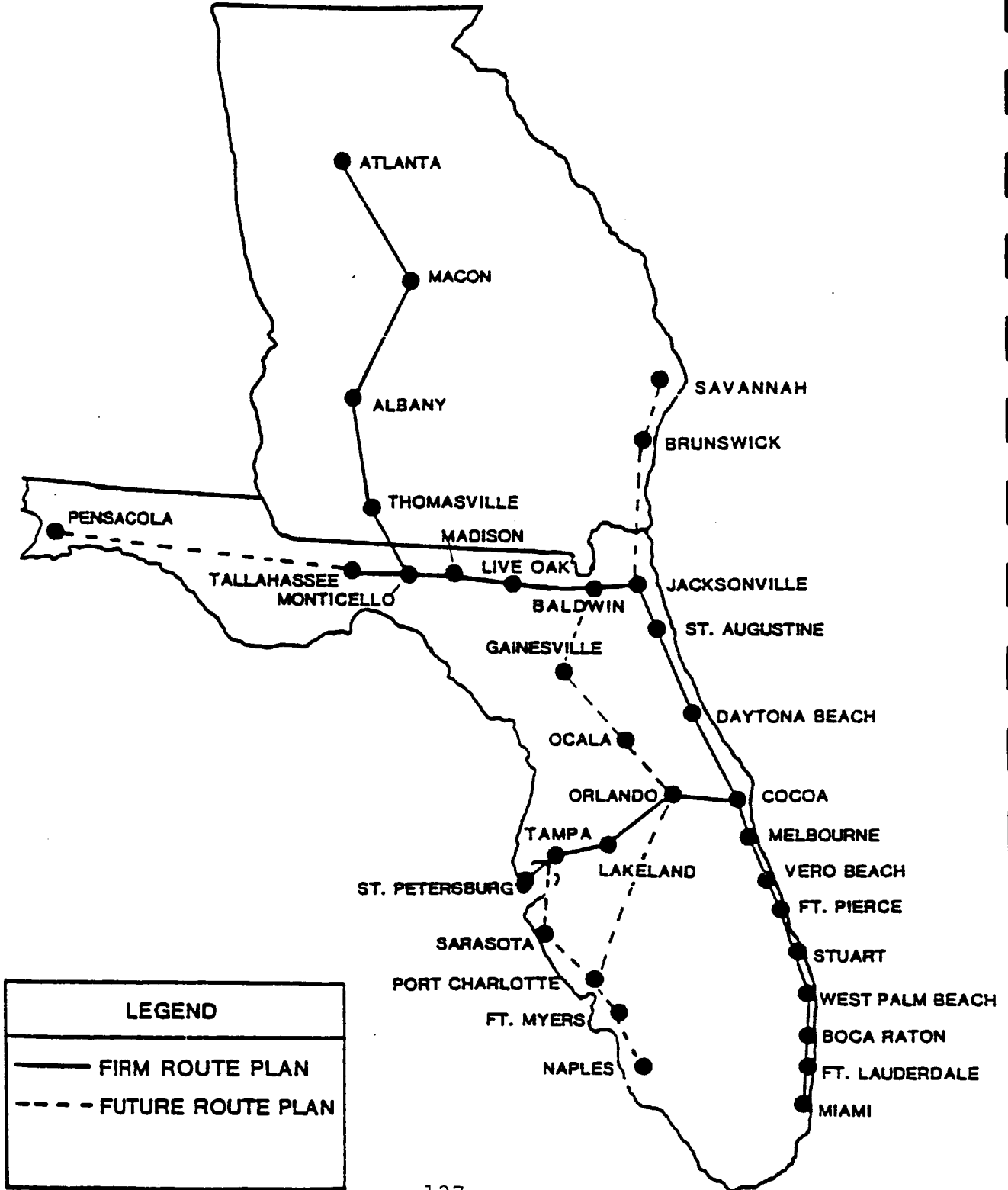
The LaserNet network provides drop and insert capabilities at major municipalities along the route to enable customer connections. At each point, Lasetnet offers equipment terminations to interface the network to the customer, directly or indirectly, depending upon the customer's preferences. At all major service points except St. Augustine/Lakeland, LaserNet is interconnected to the local telco via digital fiber optic links.

Initially, repeaters were placed at a maximum distance of 17 miles. The distance was later increased to 25 miles when field tests indicated lower loss levels than anticipated.

Ericsson was the cable supplier. The cable contains, on average, 10 single-mode fibers operating at 1310 nm. Microtel's electronics vendors for the network include NEC and ITT.

Microtel provides a wide range of services including switched network services, and private and virtual networks for voice, data and video applications. The company also has developed the LaserNet Digital Data Service Network (LDDS). Utilizing the LaserNet fiber optic system as its transmission medium, the network operates at 405 Mbps and is compatible with AT&T's Dataphone Digital Service. Microtel provides full end-user support including planning, installation, testing, and maintenance. Interfaces include VF, T-1, T-1C, T-2, and T-3.

LASERNET NETWORK TOPOLOGY



Microtel's speedy construction of its LaserNet's fiber optic system is highly advantageous. The company faces stiff competition from other major long haul fiber optic systems like U.S. Sprint, MCI, Lightnet on various parts of its Florida route. LaserNet is the only system which currently serves all the major cities on the Florida peninsula and its NTN alliance broadens its geographic scope to eventually include national fiber optic service. These factors will help Microtel to appeal to both the intra- and interstate communication needs of the businesses and government agencies the company is targeting as LaserNet's primary customers.

4.2.11 Mutual Signal

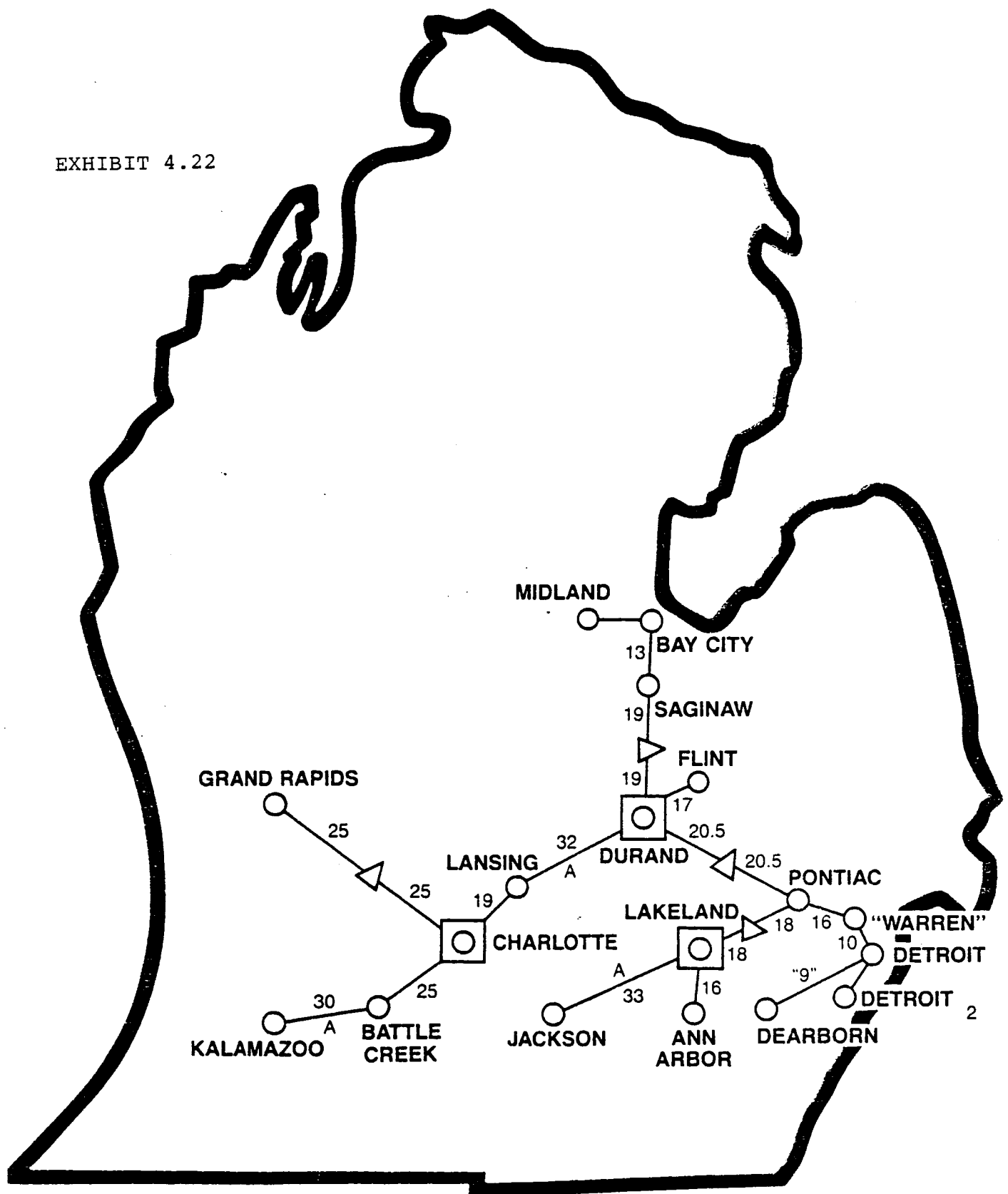
Mutual Signal Corporation, a wholly-owned subsidiary of Walker Telecommunications Corp., will build a 404-mile fiber optic network in southern Michigan. The \$30 million project is a joint venture of Mutual Signal and General Electric Credit Corporation and is scheduled for completion in late 1986.

Thirteen cities, including Detroit, Flint and Lansing, comprise the system (Exhibit 4.22). Mutual hopes eventually to link its system with NTN.

Bechtel National, a unit of Bechtel Group, is engineering and installing the system. Right-of-ways are being leased from Conrail, Grand Trunk Western Railroad and private groups.

Five pairs of single-mode fiber are being installed: three operational, two for backup purposes. Mutual Signal plans to provide voice, data and video services. Initially the system will operate at 565 Mbps. NEC will supply the transmission products, and the cable supplier for the project is Siecorm Corp.

Mutual Signal plans to lease capacity exclusively to carriers. A major carrier, Lexitel (now part of ALC), has agreed to lease 30 percent of Mutual Signal's capacity. The company will compete head-on with Bandwidth Technologies, but Mutual covers more territory. An alliance with NTN would further extend the network's scope. In the long term, Mutual Signal plans to develop, install and operate regional fiber optic networks throughout the U.S. to provide transmission capacity to long distance carriers. No specific new systems have been announced.



THE MICHIGAN SYSTEM

FIBER —
 TERMINAL ○
 JUNCTION ◻
 REPEATER △

SOURCE:
 MUTUAL SIGNALS CORPORATION,
 A DIVISION OF WALKER TELECOMMUNICATIONS
 CORPORATION.

4.2.12 NorLight

NorLight is a consortium of five electric and gas utilities serving Minnesota, Wisconsin, and Illinois which have joined together to develop a fiber optic system to handle their private communications needs and to lease the excess capacity. This venture is considered rather unique because it is the first time that a group of utilities has joined forces to take advantage of their right-of-ways. Each company has established a member subsidiary to help build, own, and operate the network. Estimated cost of the network is \$33 million.

Crucial to NorLight's plans is a favorable ruling from the Federal Communications Commission (FCC) in response to the company's request to be exempt from state regulation. The consortium feels it may have to forego construction of the system if it faces the prospect of state entry proceeding, other forms of state entry barriers and delays, or state rate regulation. The network crosses three state lines and NorLight would have to go through the entry procedure three different times -- a very expensive and time consuming process. NorLight has therefore applied to the FCC for designation as a private carrier which would then place the system under the jurisdiction of the Federal government as opposed to the three states.

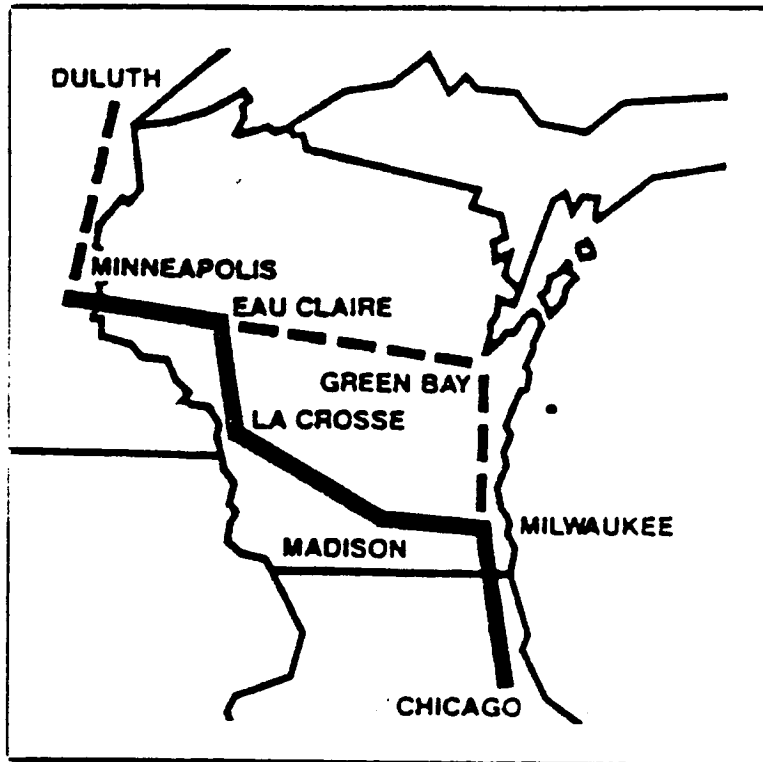
As of early March 1986, NorLight was still awaiting a ruling from the FCC regarding its designation as a private carrier and its bid for exemption from state regulation. The consortium recently requested the FCC to expedite its final decision. NorLight claims it has already lost one potential customer because of the uncertainty surrounding the network's installation. The Wisconsin Public Service Commission has allowed NorLight to continue network planning and procurement of components but has prohibited the consortium from actually constructing the network.

NorLight's fiber optic network will originally extend 650 miles, linking Milwaukee, Madison, LaCrosse, Eau Claire, Minneapolis, and Chicago (Exhibit 4.23). Further plans call for its extension to Green Bay and Duluth.

NorLight's tentative plans target the second or third quarter of 1986 for the commencement of construction, with completion by the end of 1986. This, however, is highly dependent upon the final rulings by both the FCC and the states' public service commissions. In Phase I, only fiber cables will be used to construct the network's backbone. Several locations connected during the second phase of construction, however, will be linked to the fiber backbone with digital microwave.

EXHIBIT 4.23

NORLIGHT FIBER NETWORK



A special aluminum sheathed cable will be used by NorLight to carry the fiber. Existing static wire currently strung along the power lines will be replaced with the specially designed cable containing both the 12-strand, single-mode fibers and the static wire.

NorLight recently placed two orders totaling 700 miles of cable. The bulk of the order, 420 miles, went to Alcoa Fujikura and the remainder to Phillips Cable Ltd. Ericsson Lightwave Systems recently received an order from NorLight for the 26 repeater sites and 6 terminal facilities to be used in the network.

Although the electronic equipment ordered from Ericsson operates at 565 Mbps, NorLight will initially operate somewhere between 135 and 565 Mbps. NorLight plans to seek long-term leases of bulk capacity and will select customers based upon compatibility with overall network operations. Bulk capacity will be available on the system between terminals located near major cities along NorLight's route. The services offered by the consortium will vary, and each user will have to negotiate their own individual arrangements and capacity needs. There will be no set prices or terms of service, since they differ for each user, depending upon its needs and the parameters of the capacity it selects to meet those needs. NorLight will provide operating and maintenance service for a fee to network users, but will not have any responsibility for switching or management of the users' traffic or routing unless such services are negotiated. While there will be a minimum lease of one year, NorLight anticipates that typical leases will be for a five- to ten-year term.

The basis upon which NorLight is founded could have broad ramifications for the long distance fiber optic industry. If the FCC approves NorLight's petitions, this could open the door for other utilities to follow in their footsteps. Many secondary markets, currently bypassed by major long haul fiber optic networks, could be served by other utility consortiums who will similarly join together to build a fiber optic network on their power lines. It will be interesting to note the outcome of both NorLight's and Indiana Switch's (where small independent telcos in Indiana united with an investment firm to form their own fiber optic network) bids to develop their fiber optic systems.

4.2.13 Rochester Communications, Inc.

RCI Corporation, a subsidiary of Rochester Telephone Corporation, provides general long distance and customer network services to business and residential customers. RCI operates a microwave network and plans to augment its digital service with a \$90 million fiber optic network.

The RCI Intercity Fiber Optic Network is a combination of an RCI-built 580 route-mile network extending from Buffalo to Chicago and capacity leased from other networks (Exhibit 4.24).

Construction began in April 1985 on the Buffalo-to-Chicago route and was completed in early 1986. A licensing agreement between RCI and Conrail enabled RCI to install cable along Conrail's right-of-ways in ten Midwestern and Northeastern states. On average, technicians spliced the cable every mile and installed repeater stations every 20 miles.

AT&T supplied the fiber cable which contain on average 24 fiber strands. Fujitsu and Elgin Electronics are the electronics and DC power suppliers respectively.

In addition to constructing its own system, RCI has used other measures to expand. On June 26, 1985, RCI signed an agreement with Lightnet Corporation to lease capacity from their New York-to-Washington, DC link. This move accelerated RCI's expansion into Eastern markets and eliminated the costs and problems associated with network construction.

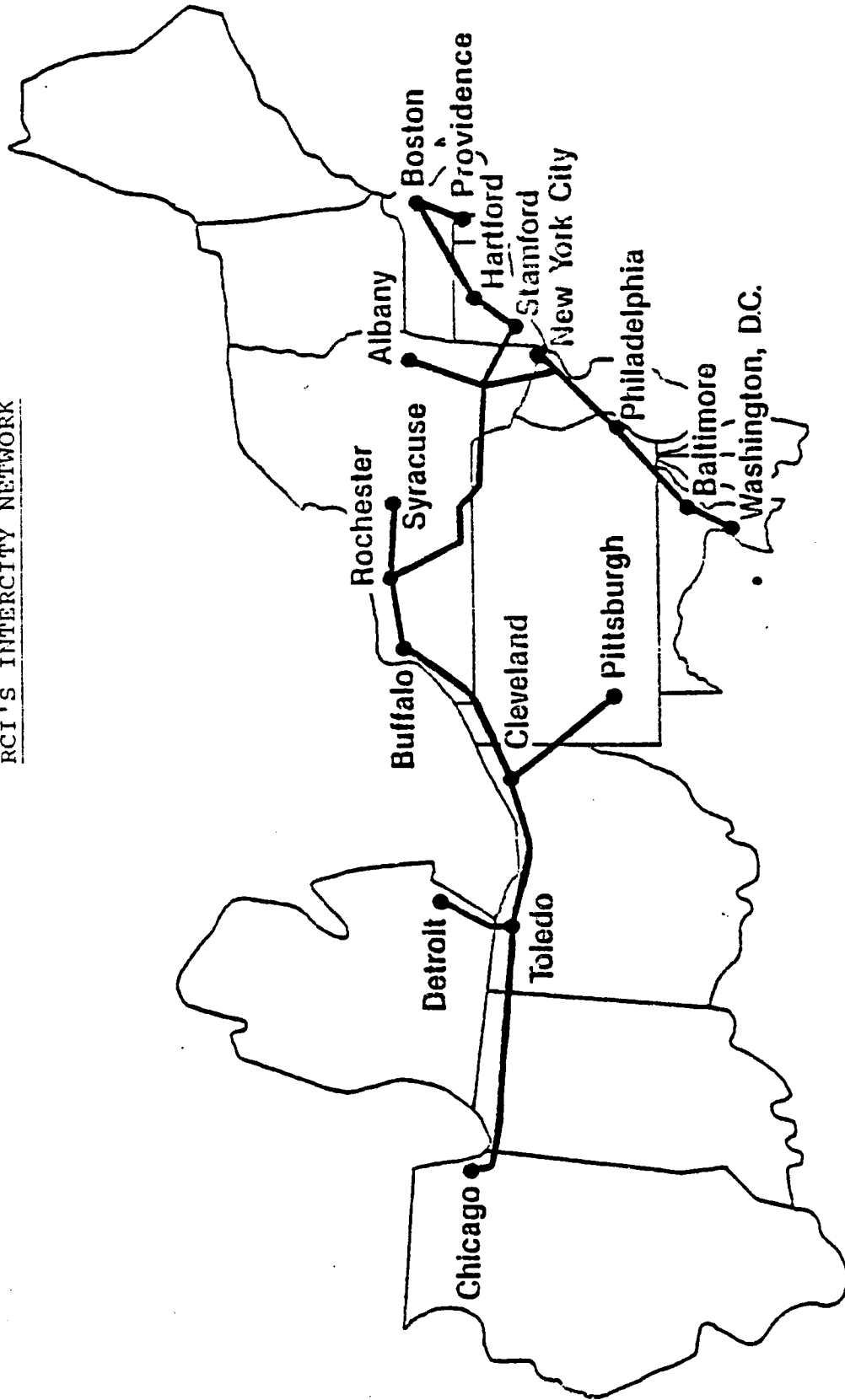
The company's expansion activities have continued. LiTel, a midwestern fiber optic network belonging to NTN, and RCI have reportedly forged an agreement to exchange traffic between the two networks. Another NTN member, SouthernNet, has also agreed to share facilities and exchange capacity from New York to Atlanta. Additionally, RCI has also reportedly approached NTN regarding the possibility of joining the consortium and perhaps interconnecting at Washington, DC. Leasing additional links from Lightnet also has not been excluded by RCI.

Operating at 405 Mbps, RCI offers several services to its customers. Customers can lease private lines within its network or use its long distance service to the continental United States, Hawaii, Puerto Rico and the U.S. Virgin Islands. To supplement its digital microwave facilities, RCI provides digital termination system facilities for intracity distribution of customer's transmissions. Other services include MTS dial-up, MTS direct access lines and T-1 service.

RCI is cautiously moving into fiber optics -- determining how this technology will best benefit the company before rushing into network construction. The fiber network will complement its existing digital microwave system and be regarded as an efficient transmission means for its current long distance service. RCI also is leasing capacity from existing networks in some areas rather than building its own -- a move that will save them time, money and avoids positioning them as another small network in a highly crowded market. It is also moving to interconnect its capacity with others. NTN, which currently lacks a Mid-Atlantic link, may find such an alliance particularly beneficial.

EXHIBIT 4.24

RCI'S INTERCITY NETWORK



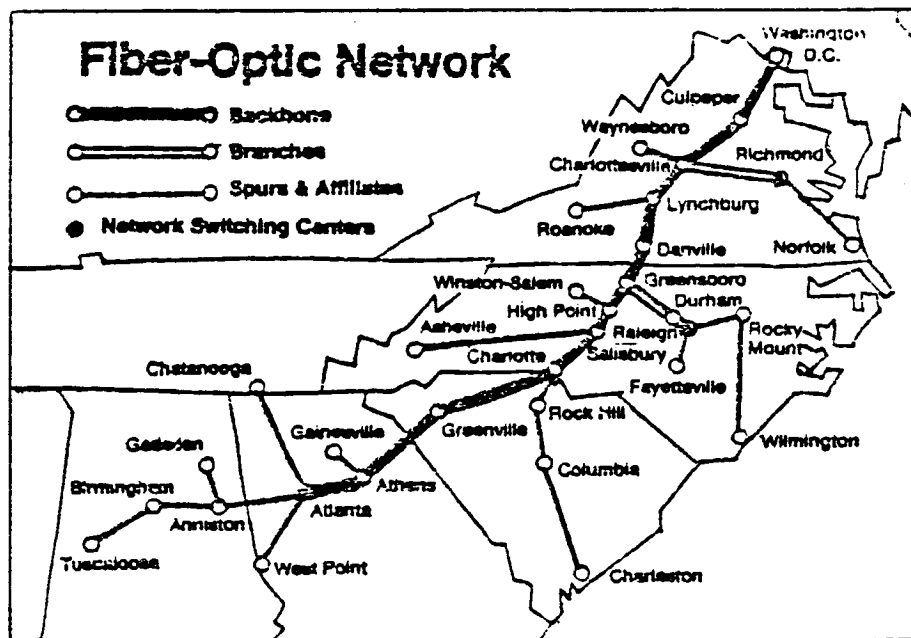
4.2.14 SouthernNet

Created in 1984, SouthernNet is a privately held corporation that currently provides long distance services to over 50,000 business and residential customers in the southeastern United States. The network is owned jointly by E.F. Hutton and 15 independent telcos, most of which have been in the long distance resell business since 1982. The projected cost for the development of its fiber optic network is \$70 million.

The 1500-mile system covers six states extending from Washington D.C. to western Alabama. Network designs call for 740 miles of backbone to be supplemented with 760 miles of spurs (Exhibit 4.25). SouthernNet also joined the National Telecommunications Network in 1985 to expand its fiber optic service nationwide and has recently agreed to share facilities and exchange capacity from New York to Atlanta.

EXHIBIT 4.25

SOUTHERNNET ROUTE MAP



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The majority of SouthernNet's system will be cut over in 1986. Construction began in October 1985 on the system's first link between Greensboro and Raleigh, NC. Siecor, AT&T, and Anaconda are the cable suppliers for the project. Each cable contains, on average, 10 single-mode fibers. The electronics suppliers include NEC.

SouthernNet will originally operate at 405 Mbps, but plans to upgrade to 565 Mbps in 1987. The network offers several services including switched voice, private voice and data lines, T1, DS-3, and DS-3C transmission, and virtual private lines.

The SouthernNet system is located in the highly competitive Southeastern corridor. The fight for customers in the larger cities, where in some instances at least three competitors face off, will be keen. SouthernNet's main advantage is its secondary city coverage, serving cities which have been bypassed by the major long haul fiber optic networks. SouthernNet offers both extensive regional and nationwide service, thus appealing to both the smaller and larger companies of the region.

4.2.15 Southland Fibernet

Incorporated in January 1985, Southland Fibernet was founded to build, own, and operate a fiber optic network as an extension of other communications services provided by its parent organization, Southland Communications. Principal investors are the Corman family, AMEV Capital Corporation, C.V. Sofinnova Partners Four, and ALTA III Limited Partnership. Other subsidiaries of Southland provide local, discounted long distance, and cellular mobile communications.

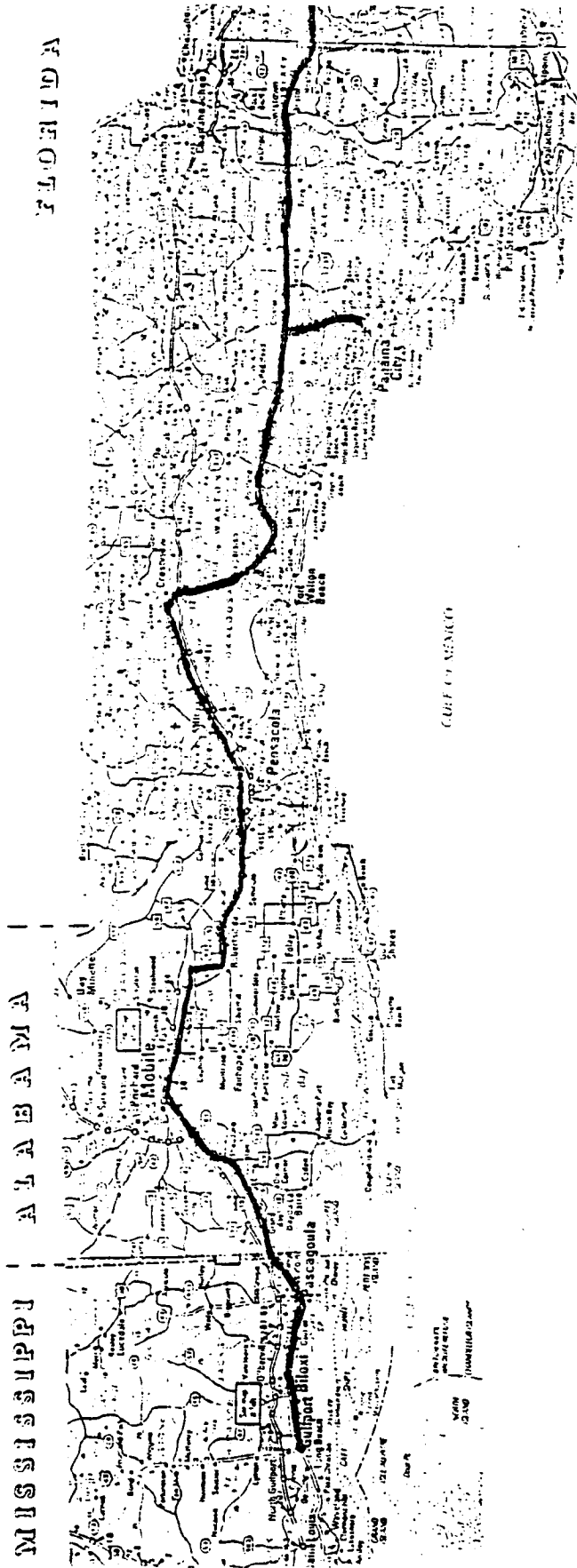
The Fibernet system stretches approximately 330 route miles along the Gulf coast (Exhibit 4.26). Beginning at Gulfport, MS, the network runs east through Mobile, AL and the Florida panhandle where it terminates in Tallahassee, FL. Since it is part of the NTN consortium, Southland plans to interconnect with its fellow members at both ends of its routes -- with Microtel in Tallahassee and LDX NET in Biloxi, MS.

The network is operational from Mobile east to Tallahassee. Targeted cut over date for the remainder of the system was mid-May 1986. Cable supplier for the project is Ericsson and the electronics vendor is NEC. Average fiber count in the cable is 10 single-mode strands.

Like most NTN members, Fibernet operates at 405 Mbps. The network offers a wide range of voice, data, and video transmission services.

EXHIBIT 4.26

SOUTHLAND FIBERNET



Phase	Segment	Route	Approx. Miles
Phase I	Segment 1	Mobile to Pensacola	Approx. 55 Miles
	Segment 2	Pensacola to Fort Walton	Approx. 68 Miles
	Segment 3	Fort Walton to Panama City	Approx. 65 Miles
Phase II	Segment 4	Panama City to Blountstown	Approx. 40 Miles
	Segment 5	Blountstown to Tallahassee	Approx. 40 Miles
	Segment 6	Mobile to Biloxi	Approx. 60 Miles

Despite its short route length, Southland Fibernet plays a vital role in the NTN network. Strategically located, Southland Fibernet ties together two regions of the country: LDX NET, which serves the Midwest and Gulf Coasts, to Microtel's LaserNet fiber optic network in the Southeast. The network also serves as a logical extension to Southland's current telecommunication operations and its customer base provides a source from which to solicit business for its fiber optic service.

4.2.16 Wiltel

Williams Telecommunications Company (Wiltel), is a subsidiary of Tulsa-based The Williams Companies, and Telecommunications Services and Systems, Inc. (formerly known as Teleconnect Co.) of Cedar Rapids. Spanning from Chicago to California, the Wiltel will build the fiber optic network and Telecommunications Services and Systems (TS&S) will provide and market the services. In June 1985, the company joined NTN, thus bringing transcontinental fiber optic service to the consortium.

The Wiltel network is extensive, covering approximately 3500 route-miles (Exhibit 4.27). After completion of the lightwave network, the company plans to extend service on the western portion of the system to Portland and Seattle using digital microwave.

The system is the first long distance fiber optic network in the United States to be installed through underground oil pipelines. Williams Pipe Line will pull the cable through empty and cleaned pipelines that are no longer needed to transport petroleum products. The cable will be protected by a flexible plastic tube about the size of vacuum cleaner hose. This, in turn, will be safeguarded by the pipeline. To install the cable, the pipeline along the fiber optic route will be uncovered approximately every 1-1/2 to 3 miles to pull and splice the cable. This construction method is estimated to save as much as 40% in construction costs and will be used for 85% of the route.

Construction started on the first phase connecting Omaha, Des Moines, Cedar Rapids, Iowa City, and the Quad-Cities in July 1985 and cutover in early 1986. Expansions connecting Chicago and Kansas City were completed in April, and Wiltel plans to finish its northern leg to Minneapolis by July. Attention will then turn to construction of the western states link where, by the end of 1986, Wiltel intends to reach Cheyenne and Denver. Wiltel plans to connect with two other NTN members -- LDX Net in Kansas City and Litel -- in Chicago.

Single-mode fiber produced by Siecor will be utilized throughout the system. The electronics vendor is NEC.

Transmission capacity will be 405 Mbps. Average fiber count is 10, but Wiltel has anticipated future capacity needs. Along with the cable installed in the pipeline, an empty interduct is placed to facilitate future cable placement if the need arises.

TS&S will be the system's major customer, utilizing capacity for their long distance services. Like the other NTN members, Wiltel offers VF, DS-1 and DS-3 service to support customers' voice and data requirements.

Joining NTN was a mutually beneficial move for both parties. Wiltel provides the valuable western link to NTN's planned transcontinental service. In turn, the company strengthens its marketing position by broadening the geographical scope of its service. With TS&S utilizing a significant portion of capacity for its long distance service, the system already has a major revenue source. TS&S, however, hopes to sign other customers to the network. Prime prospects include government agencies, common carriers, long distance resellers, corporations and universities.

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