STUDY OF THE ACTIVITIES IN FIBER OPTICS IN CANADA

submitted to

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS

SCIENTIFIC AUTHORITY:

Dr. Kenneth O. Hill
Manager,
Optical Communications Program
Communications Research Centre

PRINCIPAL AUTHOR:

Dr. John Lit
Chairman,
Department of Physics
and Computing
Wilfrid Laurier University

June 1984

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1 EXECUTIVE SUMMARY

The sudden explosion in the use of fiber optics in the past few years has been extremely remarkable. The main advocates have been coming from the telephone companies. There are a few good reasons for this development, among which are the following:

(1) The qualities of fibers have been pushed to extremely high levels. Single-mode fibers can be mass produced in long lengths. Losses can be less than 1 dB/km. Dispersion can be reduced to zero. Special fibers, such as polarization conserving fibers, can also be drawn with acceptable quality.

(2) The price of fiber has dropped tremendously.

(3) Fiber systems lend themselves easily to future expansion.

The United States has always been the leader in this field. However, Japan is poised to compete. It is among the few countries whose governments have given excellent help and leadership at the right moments to develop the country's capability in fiber optics. At present, Japan is very strong in fiber production; it has the potential to produce even more than the U.S. Its strength in local area network will soon be recognized. Further into the future, its strength in optical integrated circuits will be felt all over the world. Though not directly concerning telecommunications, its capability in, and the wide application of robotics must not be overlooked.

Although West Germany is now not a strong contender in fiber optics, in another five or six years, it may vie for the position of second in the world. This is due to the strong, continuous commitment of the Bundespost, and the possible massive conversion in subscriber loops.

Fiber optics has entered the single-mode fiber era. There will be a period during which the large bandwidth afforded by single-mode fibers will be increasingly exploited. At the same time, local area network should be developed and become well accepted. Means to simplify the circuit designs, and to increase the transmission capabilities other than by simply increasing the bit rates will have to be found, or existing methods improved.

It has been predicted that the companies that will ultimately survive in the field of fiber optics will probably be of two kinds:

(1) the giants that can put up strong and effective competition worldwide, and

(2) the small companies that have carved out their own individual niches, which are important and profitable but are too small for the giants to bother with.

The amount of fiber activity in Canada has been very outstanding, especially in view of our relatively small population. Indeed, two years ago, Canada ranked second in the world in the amount of fiber activity. Although Canada has initially responded very well to the growth of fiber optics, it will not be able to hold its position, neither as a producer, nor as a user. It has been forecast that within the next few years, Canadian activities will fall to the sixth position in the world.

The strongest group of companies in Canada is the Bell family. A distant second is Canstar. Among the countries that are very active in fiber optics, Canada holds a unique position in having so few companies that are of comparably large sizes.

The Bell group in Canada has been very successful. Bell Northern Research has supplied Northern Telecom with excellent research results, which allow the latter to develop and become one of the largest telecommunication manufacturers in the world. The Bell group could play a leading role in developing fiber industries in Canada. Among the ways they could help are:

(1) help others to do the research which they could not or would not wish to do, and

(2) encourage the smaller companies by, say, buying the products and services of Canadian companies whenever that is suitable.

It is known that Northern Telecom has been following this second way. They should aim, and should be encouraged, to carry out their leadership role even better.

Although Canada has the Bell family, it lacks a wide and strong foundation. Since it is accepted that small high-technology companies are very beneficial to Canada, and since fiber optics is an area suitable for such companies, much more effort should be directed towards the formation of such companies.

In recent years, it has been widely recognized that one of Canada's valuable resources is the manpower in universities. As shown in Section 8, fiber research in universities is extremely limited in both quantity and variety. Only a very few places have true research in fiber optics. Even fewer places are being reasonably and directly funded for their research work in fiber optics.

Aside from the telephone companies and the Department of Communications, fiber optics does not seem to have made a debut in Canada. An outstanding lack exists in government labs and agencies. This should not be the case, as one would quickly find out if one takes a look at other countries. For example, the Pentagon was reported to have said that expenditures over the next five years for fiber optics would range between $1-2 billion. It is well known that government influence can greatly change the rate of development of high technology in a country.

Optical fibers are inherently immune to electromagnetic interference; they are safe and make remote detection possible. These, and other properties of fibers and light, will make them very useful for industrial applications. It is time that Canada diversifies so that it can reap the benefits of applying optical fibers not only to telecommunications but to other areas as well.

2 METHODOLOGY

The sources of information which have been used for this study come under two main groups.

(1) Individuals

Two questionaires were sent out. The purpose of the first one was to obtain names of persons or organizations who were engaged in fiber optics activities. It was sent to individuals in selected industries and commercial establishments, government laboratores, all the chairmen/heads of the departments of electrical engineering, physics and astronomy in Canadian universities, and of some colleges, and members of the Division of Optics of the Canadian Association of Physicists. The questionnaire asked the repliers not only to indicate whether they were working in fiber optics, but also requested them to name those within or outside their organizations who might have activities related to fiber optics. Based on the results of the first questionnaire, a second questionnaire was sent out to relevant individuals, requesting specific information for the study.

Attempts were made to contact all the telephone companies. In all cases, phone calls were also made to discuss the matter. In some cases, more than one person was contacted.

In addition, many laboratory visits and personal meetings were held.

(2) Published Materials

All relevant published materials, which were available to the public and which were at the disposal of the author, were scrutinized. The principal categories were specialized newspapers, magazines, journals, reports, advertisments, and books.

As indicated above, the sources of information contained in this Report are very diverse. Even though some references to the sources have been included, no attempt has been made to include all the necessary references or acknowledgements. However, the Author believes that the information is reliable. No attempt has been made to obtain permission, neither oral nor written, to publish the information contained in this Report.

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3 TRENDS IN FIBER OPTIC TECHNOLOGIES

3.1 FIBER FABRICATION

The single technology that has affected fiber optics the most is the fabrication of the fibers themselves. The whole field could not take off before the technology could reduce the losses in fibers to less than 20 dB/km.

Fibers that are now commonly produced are either multimode or single mode, with graded index or step index. The last few years have seen very rapid advances in this technology. Initially, multimode fibers were widely accepted, even for long-haul links. Although it is still a new technology, multimode fiber technology is beginning to become outdated by single-mode technology, espcially for long distance transmission. Long-haul telephone links are now usually installed with single-mode fibers.

Intensive research is still taking place in the production of fibers. The main areas of concern are: losses, bandwidth, polarization, strength, reproducibility, and cost. Figure 3.1 is a projection of the fiber losses as a function of wavelength. It is expected that the losses will be very significantly reduced at the longer wavelengths.

The loss mechanisms of silicate glasses have been very well examined. A region of low losses is bordered by infra-red absorption of oxides at the low frequencies and by the ultra-violet edge at the high frequencies. The region of low losses is dominated by Rayleigh scattering losses and by the OH absorption lines at 950 nm and 1370 nm.

Figure 3.2 shows the losses of a silicate glass and the

FIGURE 3-1
OPTICAL FIBER LOSS

(Commercially Available)

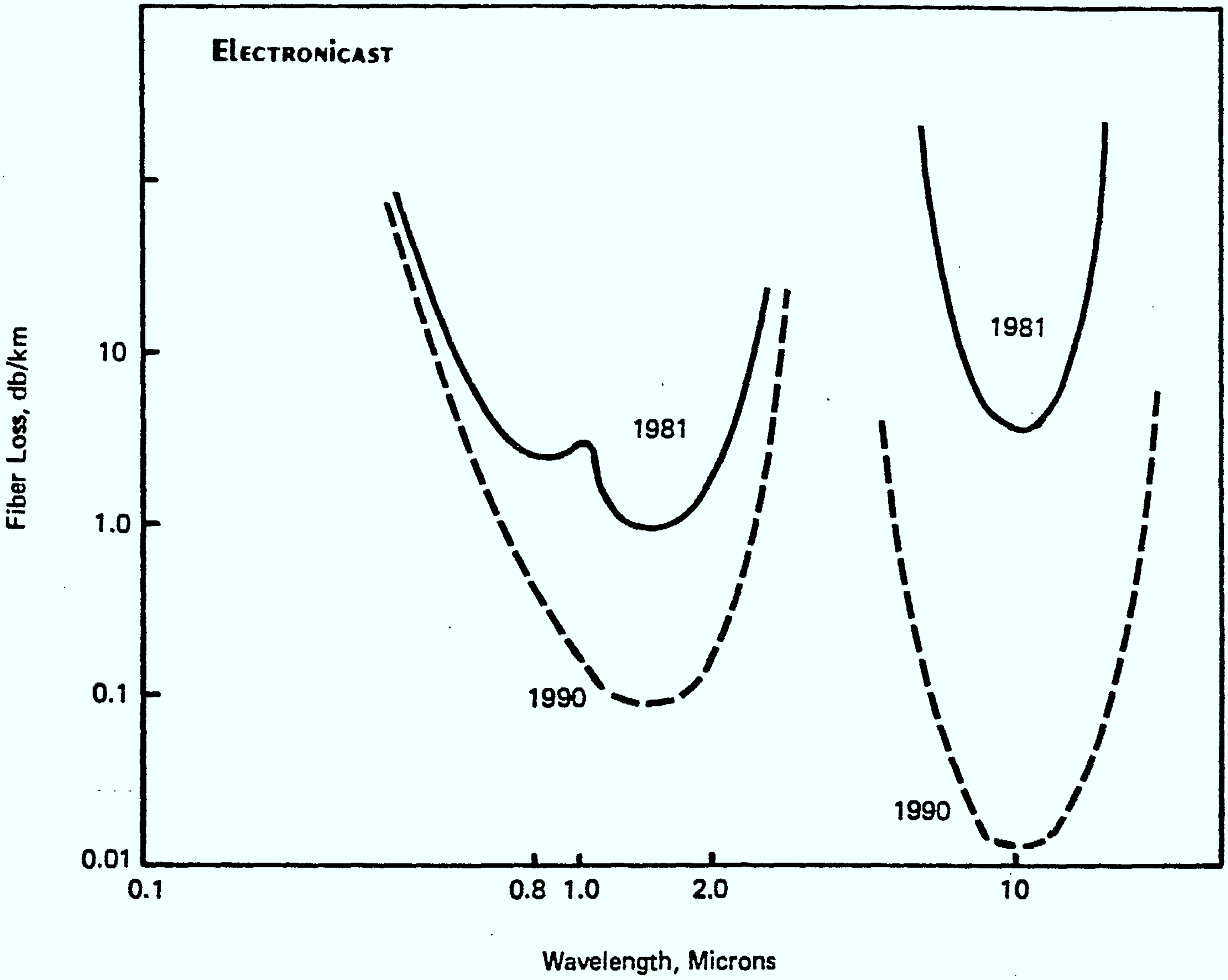
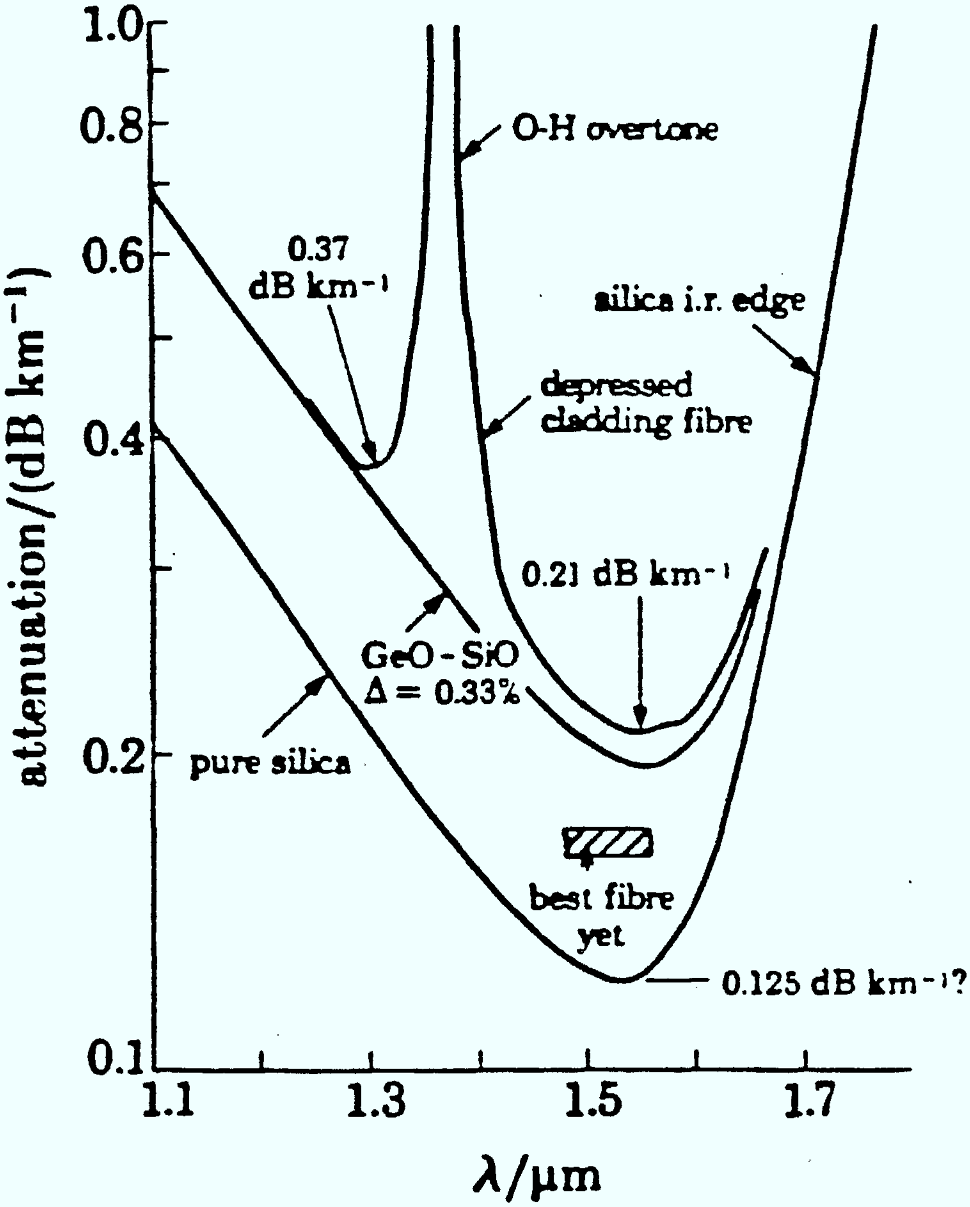


FIGURE 3.2

FIBER ATTENUATION MECHANISMS



theoretical values for pure silica (Midwinter, 1984). It should be noted that some silicate glasses could have Rayleigh scattering losses lower than pure silica (Schroeder et al. 1973).

Absorption losses associated with dopants can be serious. The use of boron and phosphorsus to respectively decrease and increase the refractive index is well under control. The effects of germanium are related to other factors such as drawing temperature and speed, as well as fiber structure (Ainslie et al. 1982).

The effects of H are very complex, and are being actively studied. They depend on the temperature and the composition of the glass (Beales et al. 1983, Muchizuki et al. 1983, Uchida et al. 1983).

Efforts are also being made to change from a batch process to a continuous process. This will greatly increase the production efficiency with reduction in costs.

Some companies researching in fiber fabriction may wish to avoid infringing Corning's process and material patents. Recently, Corning has been pressing hard on their patent rights. It has successfully claimed that other companies had infringed their primary patent (U.S. Patent No. 3,659,915) and sold their fibers to the U.S. government. That patent is considered to be a "breakthrough" patent, because the process for making doped fused silica core or cladding with pure fused silica was previously unknown. This was also the patent (Canadian Patent No. 951,555) which Corning claimed Canstar had broken. On April 8, 1984, the Federal Court in Toronto ruled in favour of Corning. In early

April, 1984, the company went before the International Trade Commission in Washington to complain that Sumitomo was infringing on that patent. As a result, the ITC has launched a full investigation.

The patent mentioned above and some others are very far-reaching. Because Corning is so aggressive in protecting its rights, and because fiber production is very lucrative, it is not surprising at all that some companies are intensely researching its production.

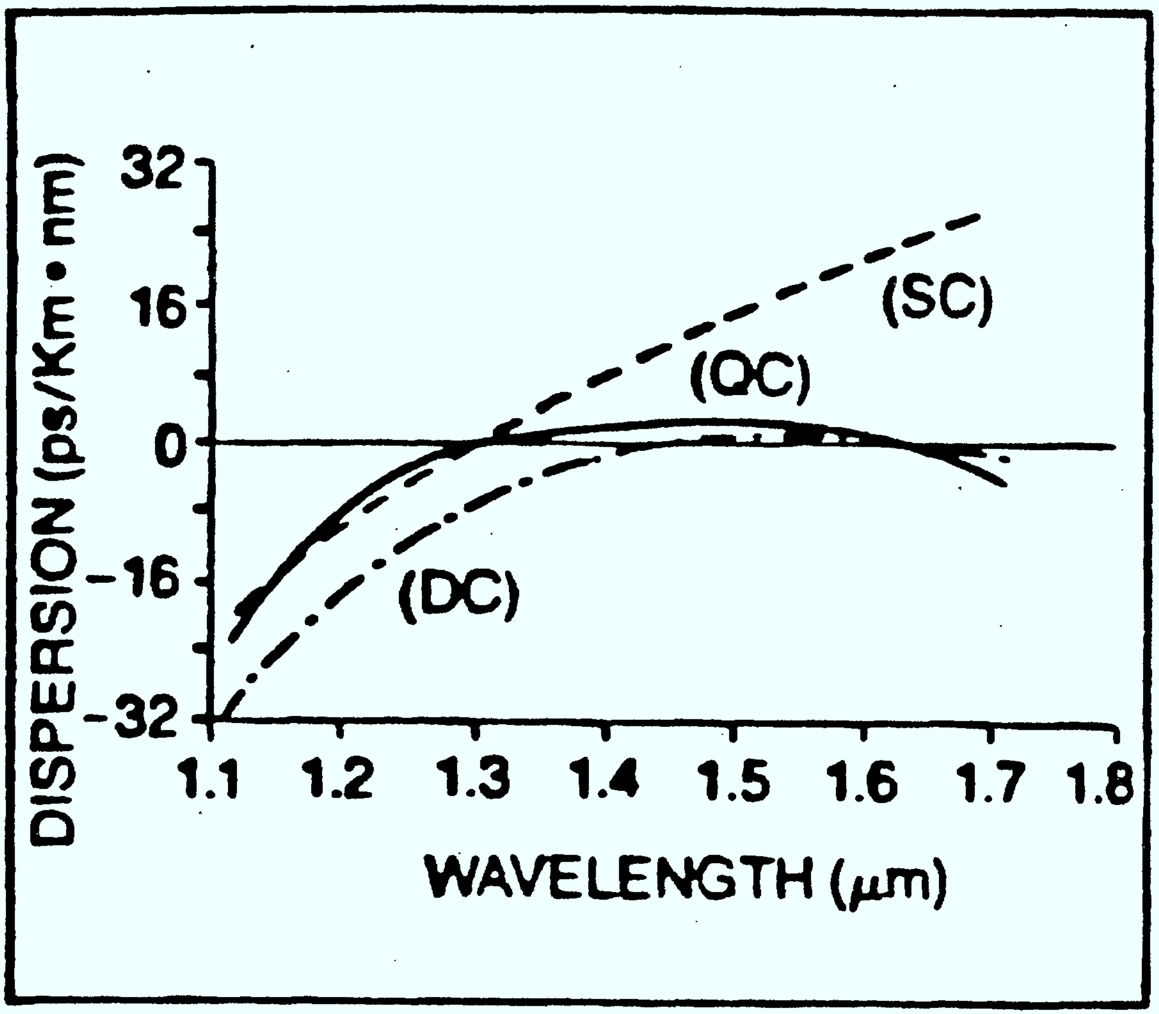
In addition to trying to reduce losses in fibers, there has also been research to improve other parameters of fibers. In 1983, Bell Laboratories developed the quadruple-clad fibers which combine low-dispersion with low losses over the whole range from 1300 nm to 1600 nm. Figure 3.3 shows dispersion as a function of wavelength for single-clad, double-clad and quadruple-clad fibers.

Polarization-preserving fibers have also been developed. A recent type attenuates the undesired polarization mode by tunnelling loss after the propagation constants of the two polarization modes have been split by either high stress or geometrical birefringence.

Different fiber manufacturing processes have been used. In general, they can be classified into five major groups. (1) One of the early processes was the double crucible method (Newns et al. 1977); purified constituents of crown or borosilicate glass were melted and refined and then fibers were drawn from a double crucible. (2) Corning Glass Works uses highly pure constituents

FIGURE 3.3

DISPERSION VERSUS WAVELENGTH



SC = SINGLE CLADDING
DC = DOUBLE CLADDING
QC = QUADRUPLE CLADDING

such as $SiCl_4$ and $GeCl_4$ and allowes them to react in vapour phase to produce high-silica glass particles which are then collected on the outside of a mandrel (Flamenbaum et al. 1972). In this outside vapour-phase oxidation process (OVPO), the type of soot thus produced is separated from the mandrel, sintered and then drawn into fibers. (3) In the OVPO process, a flame is used for the heating. Phillips Company used microwave plasmas to achieve reaction and deposit the product inside a silica tube (Kuper et al. 1977). (4) Another modification of the OVPO has been very successful. In the modified chemical vapour deposition process, instead of having the constituents react outside a mandrel, the Bell Laboratories has them react inside a silica tube (MacChesney et al. 1974). The particles are synthesized, deposited, and then sintered by an oxy-hydrogen torch along the tube. The tube thus produced is collapsed and drawn into fibers. (5) A more recent method is the vapour-phase axial deposition process developed by the Nippon Telegraph and Telephone Laboratories (Izawa et al. 1977). This is very similar to the outside vapour-phase oxidation process, except that the soot is deposited onto the end and not the side of a seed rod or mandrel. At present, the two most outstanding processes are the modified chemical vapour deposition process and the vapour-phase axial deposition process which will be considered in greater detail in the following sections.

3.1.1 MODIFIED CHEMICAL VAPOUR DEPOSITION

The modified chemical vapour deposition (MCVD) process was developed by the Bell Laboratories. Figure 3.4 is a schematic diagram of the process. Because the constituents react inside a tube, the process is inherently a clean process, as long as the gaseous constituents and the support tube are clean. Consequenntly, even the early preforms produced by this method were of reasonable quality.

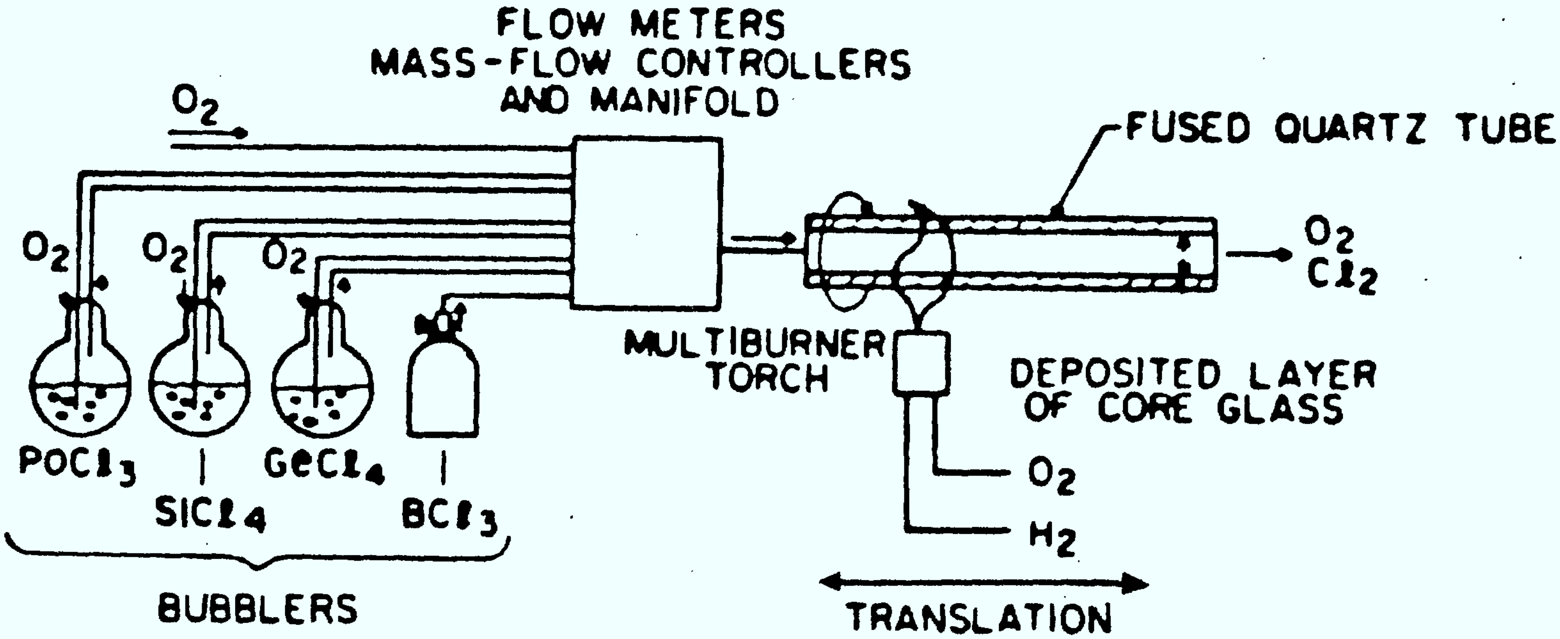
As in all fabrication processes, losses in fibers produced by this process must be kept as low as possible. The major sources of these are impurity absorption and scattering, intrinsic ultra-violet and infrared absorption, Rayleigh scattering, and waveguide effects.

Of prime importance is the OH absorption. There are a few major sources: hydrogen-containing contaminants in the reacting gaseous constituents, air leaks from the surrounding atmosphere, and OH diffused from the supporting tube. One purification method is to promote photochemical reduction with chlorine, and removing the resulting HCl. The methane, which is the chief contaminant in the oxygen gas, is oxidised with the help of a platinum catalyst; this is followed by the removal of the water thus formed. Diffusion of OH from the supporting tube is prevented by depositing a thick barrier layer (MacChesney et al. 1974, Kawachi et al. 1977).

The bandwidth of a single-mode fiber is limited by the dispersion, namely the material and waveguide dispersions. It

FIGURE 3.4

SCHEMATIC DIAGRAM OF MCVD PROCESS



has been shown that for most of the compositions of today's fibers, the graph of the refractive index as a function of wavelength has an inflection somewhere between 1270 nm and 1340 nm, where its second derivative with respect to wavelength is zero (Lin et al. 1978). The position of this particular wavelength can be shifted by compensating the material dispersion with waveguide dispersion, which is controlled by the fiber core radius. By using this method, in a germanium oxide/silica fiber, the zero-dispersion wavelength can be shifted to 1600 nm (Cohen et al. 1979).

In the case of multimode fibers, dispersion can be controlled by profiling the refractive index distribution. Since this can be done in the MCVD process, control of dispersion in multimode fibers is also possible.

The mechanism responsible for deposition in CMVD is thermophoresis (Simpkins et al. 1979). This means that the deposition rate can be changed by the temperature gradient in the gas stream and the gas flow rates. Deposition rates greater than 1 gm/min have been obtained (Simpson et al. 1980).

3.1.2 VAPOUR-PHASE AXIAL DEPOSITION

In the vapour-phase axial deposition (VAD) process, the reactive gases are added to the end of a rod. It offers the possibility of continuous production. It was developed at Ibaraki Electrical Communication Laboratory of Nippon Telegraph and Telephone, which obtained a U.S. patent in May 1976, under Patent No. 3,957,474. Another axial deposition patent (No. 3,966,446) was obtained by the Bell Telephone Laboratories in June, 1976. Sumitomo Electric Industries also obtained a patent (No. 4,135,901) for depositing materials at the end of a rod.

Figure 3.5 shows a diagram of the VAD as recorded in the U.S. Patent No. 3,957,474.

Fibers produced by the VAD process possess superior qualities. As early as 1980, NTT reduced the OH content to 1 part per billion, and produced fibers with lossess of 0.04 dB/km at 1390 nm (Moreyama et al. 1980, Hanawa et al. 1980). Table 3.1 shows the transmission characteristics of a VAD fiber, 4.12 km long, assuming 6 dB bandwidth (Nakahara et. al., 1980).

Besides having low minimum losses, VAD fibers do not have high loss peaks. Figure 3.6 shows the loss as a function of wavelength for a VAD multimode graded-index fiber. The loss is low throughout the range 1200 to 1600 nm. In what follows, a brief discussion of the VAD process and the ways to obtain high quality fibers are presented.

Figure 3.7 is a schematic diagram of a typical set-up to produce a VAD preform (Inagake, 1981). Fine glass particles

FIGURE 3.5

VAD PROCESS

U.S. PATENT 3,957,474

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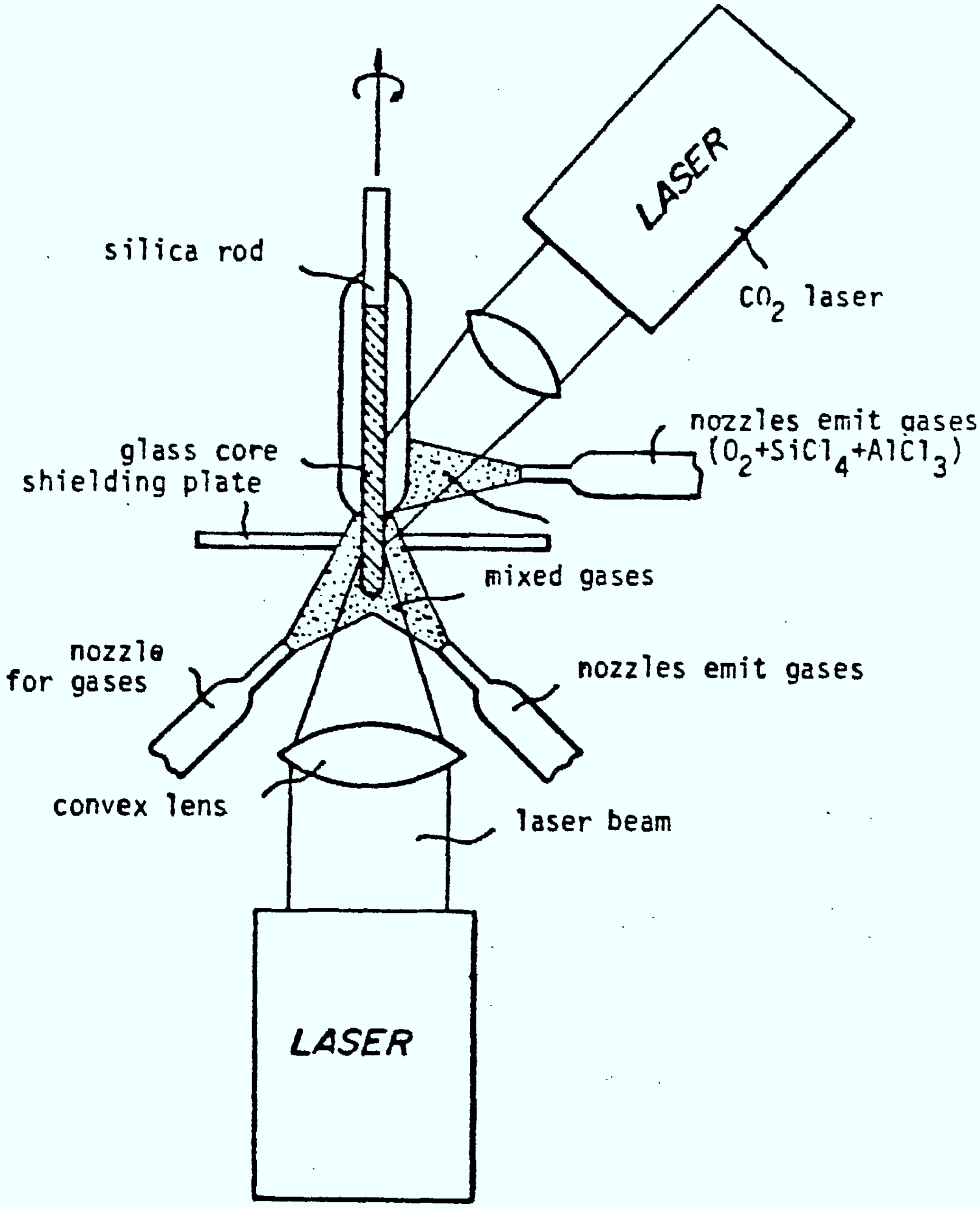


TABLE 3.1

TRANSMISSION CHARACTERISTICS OF VAD FIBER

Wavelength	Loss	Bandwidth
890 nm	2.51 dB/km	821 MHz-km
1290 nm	0.86 dB/km	5244 MHz-km
1310 nm	0.80 dB/km	6530 MHz-km

FIGURE 3.6

LOSS SPECTRUM OF VAD GRADED-INDEX FIBER

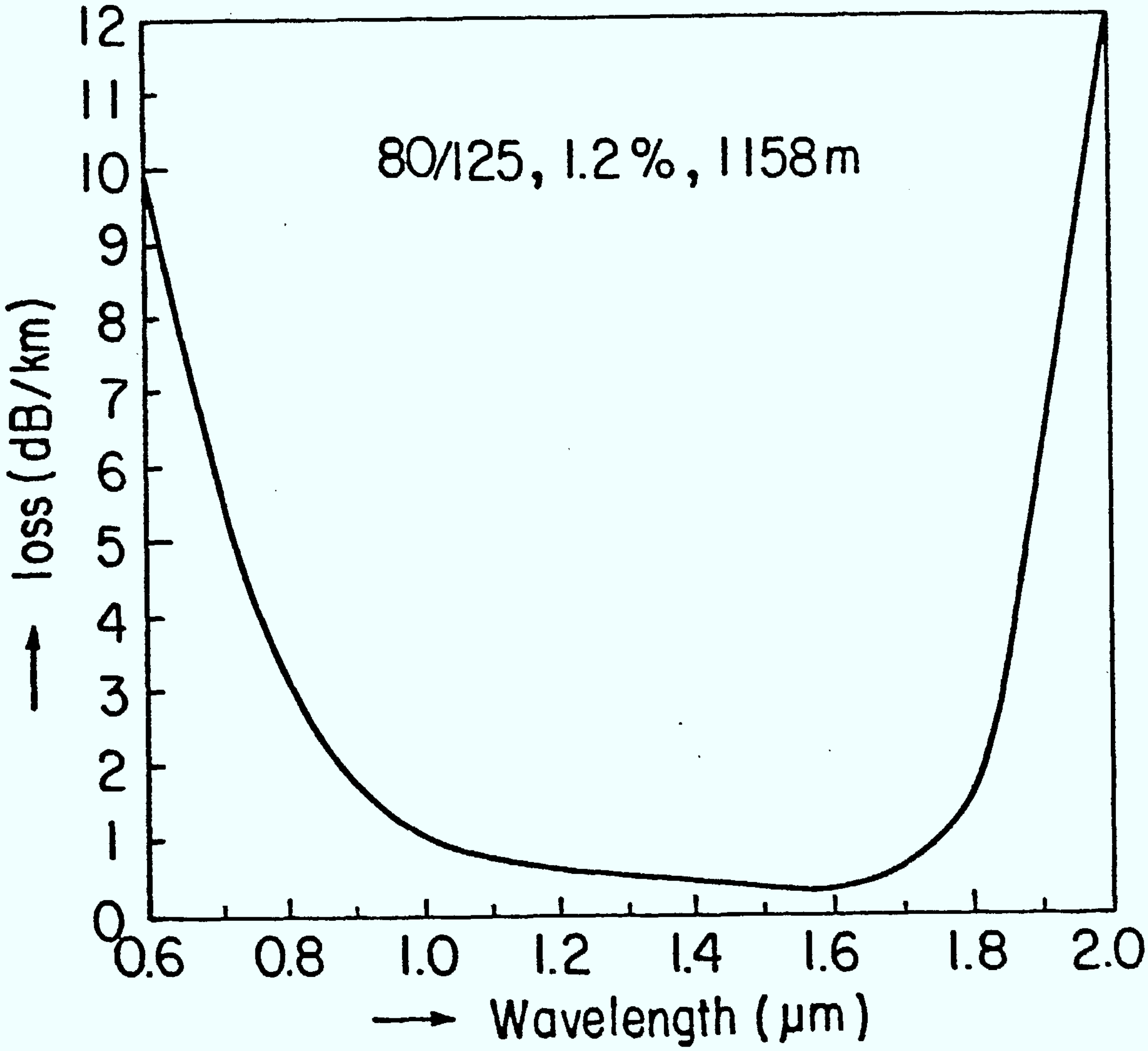
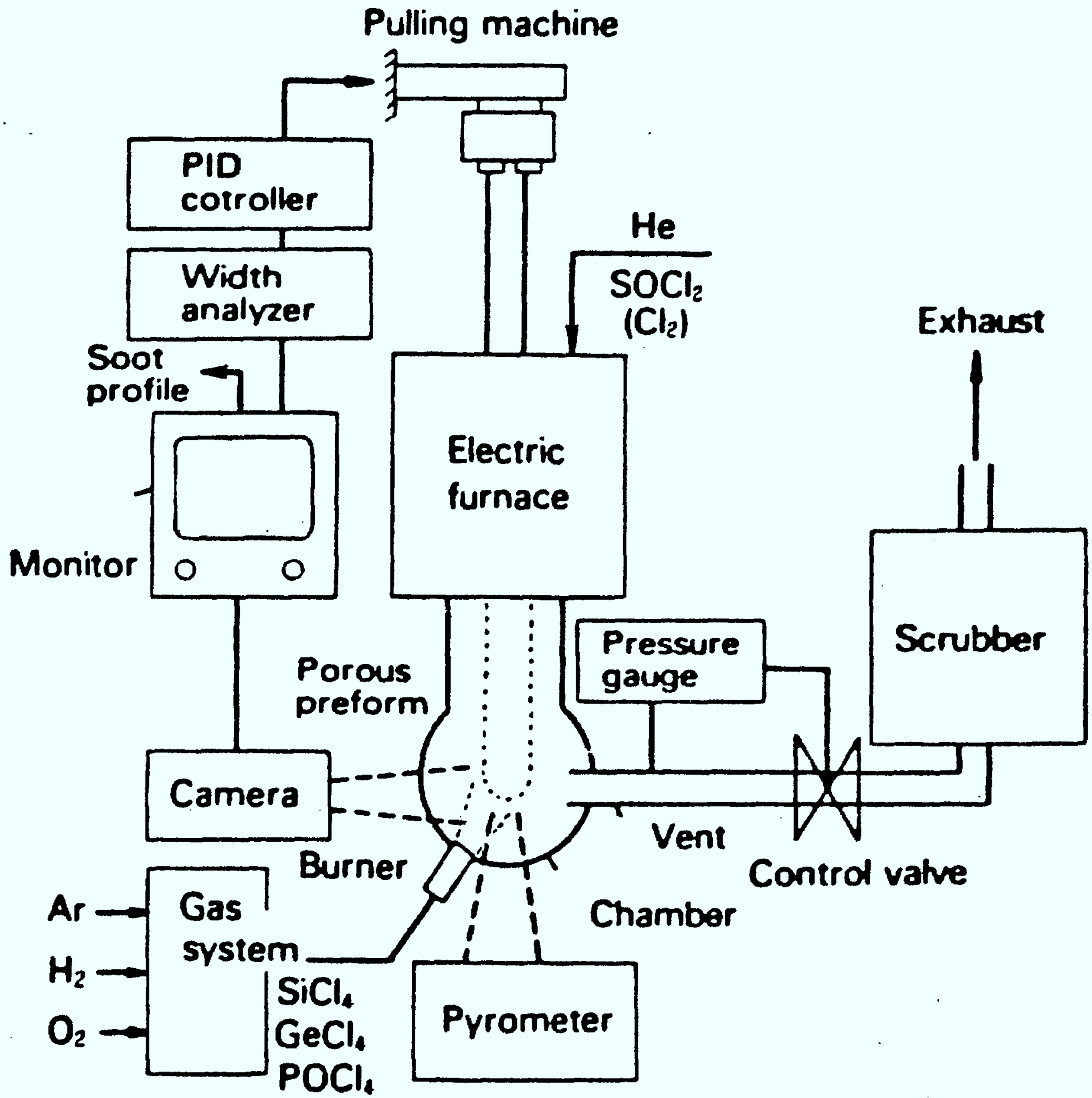


FIGURE 3.7

SCHEMATIC DIAGRAM OF VAD PROCESS



synthesized from a mixture of gases by the oxy-hydrogen flame are deposited onto the end of a seed rod, thus growing a porous preform axially. The growth of the preform is constantly monitored by an ITV camera. The principal steps of a typical process are shown in Table 3.2 (Inada, 1980), and some of the typical data and parameters of such a process are given in Table 3.3 (Inada, 1982).

Because of the oxy-hydrogen flame used for the synthesis, the preform is contaminated with OH ions. A dehydration process using $SOCl_2$ has been applied. Figure 3.8 shows the results of attempts to eliminate the OH ions (Niizeki, 1981).

The refractive index profile of a VAD preform is difficult to control. It is affected by many factors, among which are the flow rates of materials, shape of soot preform, temperature of the surface of the soot, and burner configuration and position. To complicate the matter, the dopant concentration profile in a porous preform changes when the porous preform is consolidated, because the soot density generally decreases with radius (Kuwahara et al., 1981).

The bandwidth of a VAD fiber was initially rather narrow. Recently, a 6.7 GHz.km was achieved at 1300 nm (Nadahara et al. 1980, Edahiro et al. 1980).

VAD is very adaptable to making single-mode fibers. Due to the fact that it does not have a central dip in refractive index, the absolute difference between the refractive indices of the core and the cladding does not have to be as high as it would have to be if there were a central dip. Because a smaller refractive

TABLE 3.2

TYPICAL VAD PROCESSES

Soot preform	Deposition of fine glass particles by flame hydrolysis reaction
Dehydration treatment and sintering	Dehydration by Cl_2 or $SOCl_2$ at about 1500 °C. The rod diameter after sintering is about 25 mm.
Preform elongation	In an oxy-hydrogen flame, elongated rod diamter is about 10 mm
Jacketing	Thick wall silica tube with rod-in-tube method

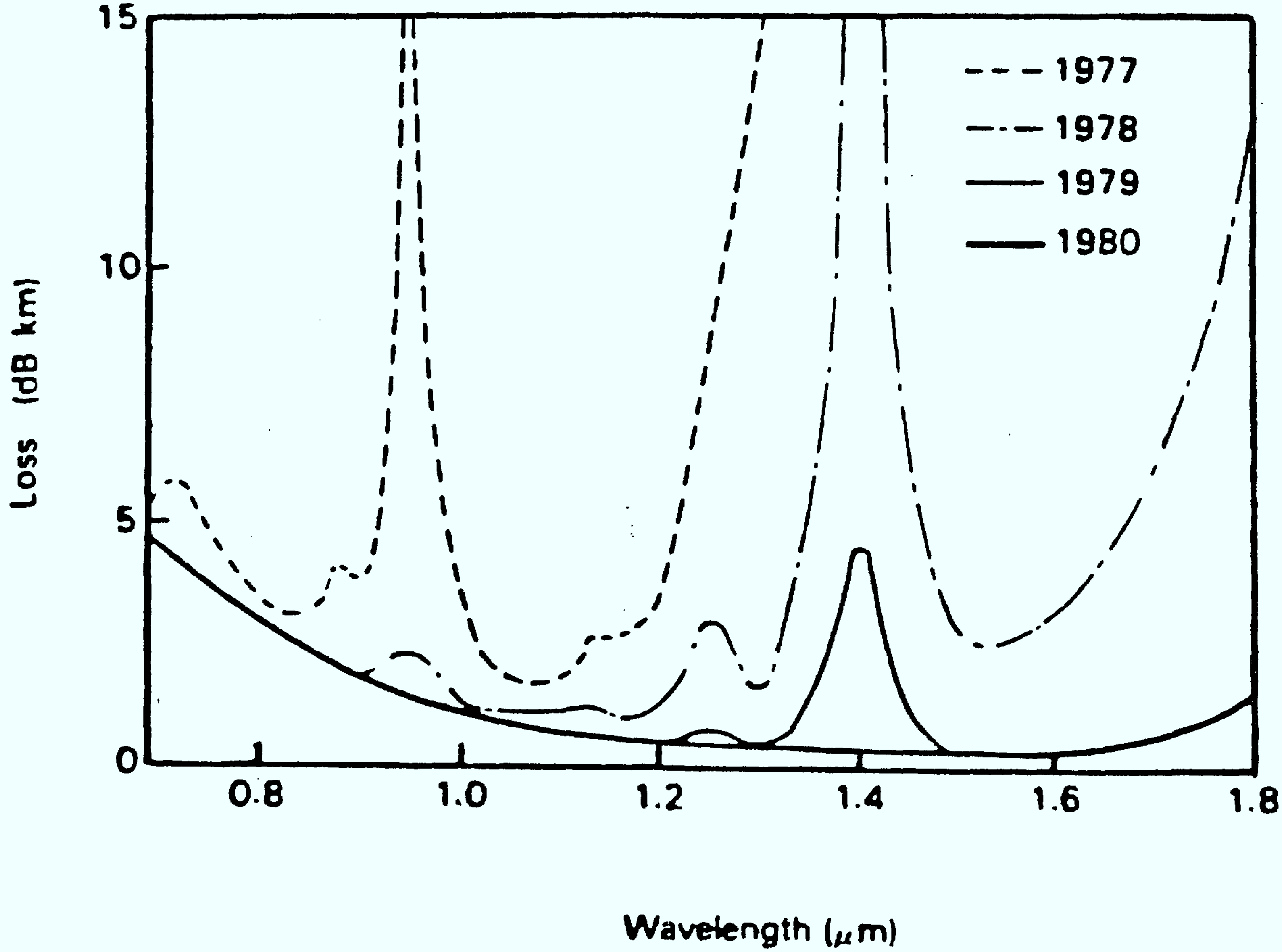
TABLE 3.3

TYPICAL PROCESS PARAMETERS AND THE TOP DATA

Deposition speed	2.0 gm/min, 0.5-1.7 gm/min
Deposition efficiency	60-80 percent
Diameter (as-grown)	
Porous preform	58 mm x 350 mm, 60 mm 70 mm, 52 mm x 300 mm
Transparent preform	23 mm, 24 mm, 25 mm, 30 mm
Continuous fiber length	100 km, 21 km, 30 km

FIGURE 3.8

PROGRESS OF LOSS OF GRADED-INDEX VAD FIBER



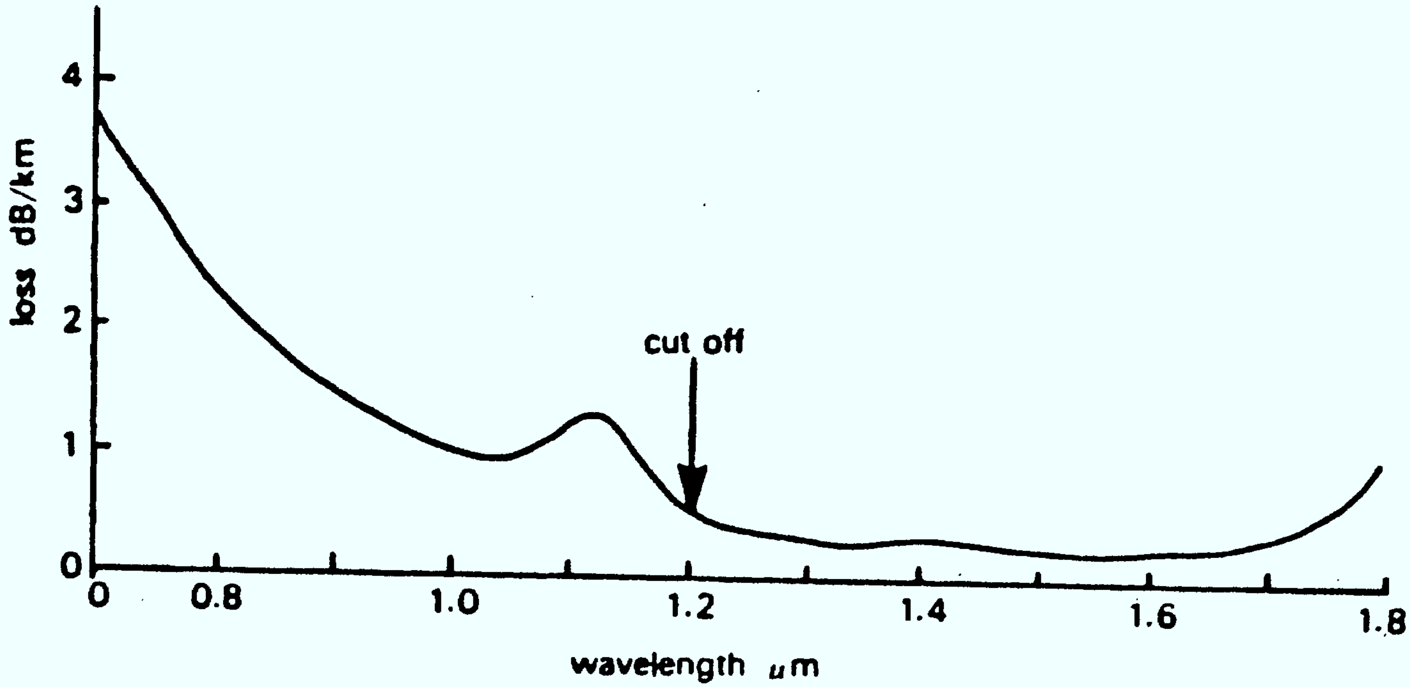
difference means lower Rayleigh scattering loss, this is an important advantage of the VAD process. Figure 3.9 shows the loss of a VAD single-mode fiber as a function of wavelength (Tomaru et al. 1981). The fiber had a 0.25% relative refractive index difference; its core diameter was 8.9 microns, and the cladding diameter was about seven times as large. The higher order cut-off wavelength was about 1.2 microns. The hump around 1.1 micron was attributed to the excess losses due to the first high order mode. Losses at 1300 nm and 1550 nm were respectively 0.35 and 0.2 dB/km.

A major difficulty with VAD is to maintain a constant diameter. However, in 1982, Sumitomo developed a technique and succeeded in drawing 300 km of fiber from a single VAD preform which measured 2.4 cm in diameter and 150 cm in length.

VAD promises to be an excellent fiber production process. Its deposition is much faster than MCVD. It poses very stiff competition to the modified chemical vapour deposition process.

FIGURE 3.9

LOSS SPECTRUM OF ULTRA-LOW LOSS VAD SINGLE-MODE FIBER



3.2 TRANSMITTERS AND RECEIVERS

Early fiber optic transmission systems used semiconductor laser and LED as sources. In the 800-900 nm region, they are made with GaAlAs on GaAs. For the 1300 nm, GaInAsP on InP may be used. The output of semiconductor lasers for digital transmission usually has a few longitudinal modes with a spectral range of 3-5 nm. To control the spectral output, a wavelength selection mechanism is required. Recently the cleaved coupled cavity laser has been investigated (Ebeling et al. 1983). Two lasers are formed on a common chip which has been cleaved and slightly separated longitudinally. It can be so made that the modes of the two lasers will interact to allow only one line to lase. Wavelength selection can also be achieved by using a grating to produce distributed feedback (Westbrook et al. 1983). These methods produce single longitudinal mode emissions.

Very high spectral purity can be produced by using the 1520 nm line of a HeNe gas laser with extremely high spectral purity to injection lock a semiconductor laser. Linewidths of 10-100 kHz have been produced (Wyatt et al. 1982 and 1983).

The common receiving systems use PIN photodiodes or APD as detectors. In the 800-900 nm region, Si APD is convenient. For the 1300 nm, Ge APD or GaInAs PIN hybrid integrated with GaAs FET preamplifiers may be used.

Poisson statistics shows that about 21 photons per bit average would be required for binary detection. Because all the detectors mentioned above require more than 1000 photons per bit, there is much room for improvement in receiver sensitivity. Recently, to improve the sensitivity, III-V materials (InGaAsP and InGaAs) have been used to make APD's (Ando et al. 1983). Similarly CdHgTe has been used (Meslage et al. 1983). But both these routes are still very far away from technological success.

It is known that near quantum limit detection could be possible with homodyne or heterodyne reception. To achieve this, sources with extremely high purity for transmitter and receiver local oscillators have to be used. With the production of a highly pure 1520 nm HeNe line and the success in producing narrow semiconductor lines (Wyatt et al. 1982 and 1983a), this appears to be feasible. Indeed, a homodyne phase shift key receiver has been shown to have a maximum detection sensitivity of 22 photons per bit (mean); it operated at 140 Mb/s at the wavelength of 1500 nm (Malyon et al. 1983). Similarly, a heterodyne system with phase shift key modulation also operating at 140 Mb/s at 1500 nm has successfully operated over a distance of 109 km; the receiver sensitivity was about 88 photons per bit (Wyatt et al 1983b).

3.3 WAVELENGTH DIVISION MULTIPLEXING

Wavelength division multiplexing (WDM) can increase the transmission capability of a fiber system without having to install extra fibers. It allows full duplex transmission through a single fiber, and reduces the cost of subscriber loop systems, while increasing its flexibility.

The commercially available WDM invariably uses dichroic filters, usually for a wave in the short wavelength region (between 700 and 900 nm) and one in the long wavelength region (between 1000 and 1600 nm).

Most of the published works came from Japan. In order to have good WDM systems, the multiplexers should be able to separate wavelengths close together with very low crosstalks. However, before they can be effectively used, stable narrow bandwidth sources must be developed.

Nippon Telegraph and Telephone has been developing MDW since 1975. It has also developed techniques to control the wavelengths of light sources as well as systems for subscriber loops, using WDM. Such systems can provide services in voice, video, data and digital facsimile, which could be used for TV conferencing and CATV. Besides NTT, Hitachi, Mitsubishi and Fujitsu have also developed laser diodes for WDM. This is another area in which Japan will be a potential leader.

WDM has been actively pursued in the past, when transmission fiber systems had multi-mode fibers. In Canada, they have been used in the Elie-St. Eustache and in the Alberta Government

Telephone systems.

In the past two years, single-mode fibers have been widely accepted and installed in different systems. Because of this, the installation of systems with WDM is expected to slow down. However, this should only be a temporary phenomenon. As Thomas L. Leming, MCI Senior Vice-President, recently expressed at the Newport Conference on Fiber optic Markets (held by the Kessler Marketing Intelligence in Newport, Rhode Island, on October 18 and 19, 1983), developments in higher bit rates and in wavelength division multiplexing will open up a host of services that will include digital post offices, video teleconferencing, LANs directly accessing long-haul systems and computers accessing computers.

3.4 INTEGRATED CIRCUITS

Fiber optic systems will remain hybrid or continue to be expensive unless suitable mass production processes are developed to produce optical integrated circuits. The first serious attempt at integration used lithium niobate. Gallium arsenide lasers were used as sources and silicon photodetectors were used at the detection end.

Vapour deposition processes are now being developed, using indium, gallium arsenide and phosphide on a gallium arsenide substrate. Because InGaAlAs/InP could be used to make sources, detectors and waveguides, it is hopeful that such research could lead to monolithic optical integrated circuits.

In Japan, nine companies are working under a $79 million government program to develop optical integrated circuits. If they succeed, it will greatly strengthen Japan's position not only in fiber optic communications, but also in many other related areas. The potential financial benefits can hardly be estimated at this time.

3.5 SYSTEMS

Fiber optic communications began with wavelengths in the 800-900 nm region. Because of lower losses and dispersion, 1300 nm is now commonly accepted. To examine the present systems and to project into the near future, a part of our discussion follows the work of Midwinter (1984).

At the end of the seventies, multimode graded-index fibers were preferred. With the improvement of fiber fabrication technology and the success of single-mode fiber devices, most long distance systems are now installed with single-mode fibers.

In the U.S., the first single-mode fiber system to carry live telephone services was cut over in September 1983. It was a 37 km repeaterless 90 Mb/s system linking two central offices of Continental Telephone of New York in Norwick and Sidney. The 6-fiber cable and the electronics were provided by Siecor Corp. and by ITT Telecom respectively.

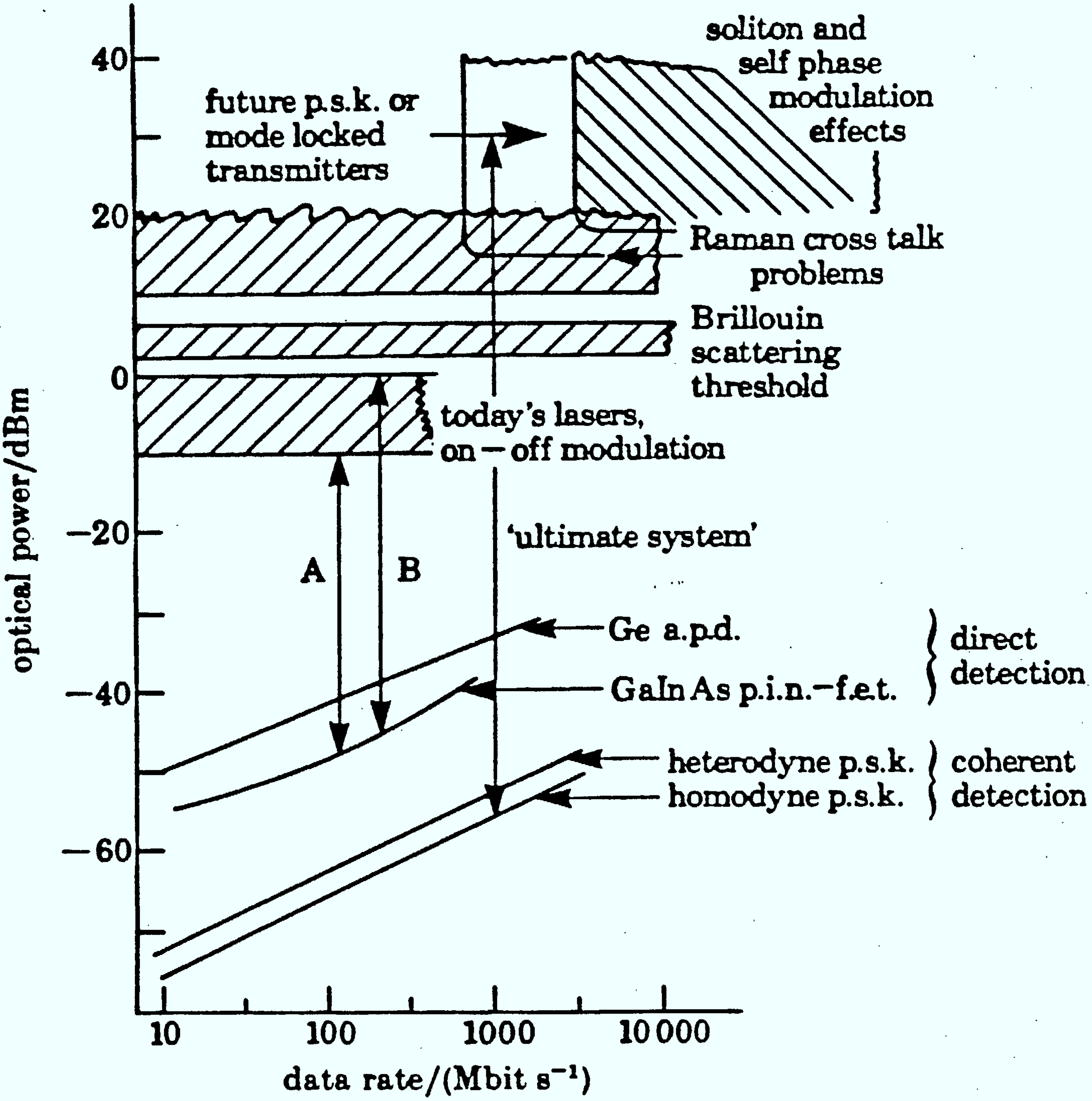
A record-breaking 161 km repeaterless 420 Mb/s system was installed in Holmdel, New Jersey, by AT&T Bell Laboratories in October 1983. The source was an InGaAsP cleaved coupled cavity laser, operating at 1500 nm. The receiver had a three-layered APD.

In January 1984, AT&T Bell Laboratories announced another technological achievement. It was a 1 Gb/s signal transmission over a 120 km repeaterless link, using again a cleaved coupled cavity laser and a three-layered APD.

Figure 3.10 shows the present situation of sources and

FIGURE 3.10

POWER BUDGET FOR PRESENT AND FUTURE SYSTEMS



detectors. It also shows the possibilities in the future. It should be noted that the system may be limited by the maximum input power that could be fed into the system; it may not be limited by the actual powers of the sources, but by the Brillouin and Raman effects. However, it may also be limited by the detection sensitivity. As indicated, coherent detection with homodyne phase shift key modulation may be used for the "ultimate system".

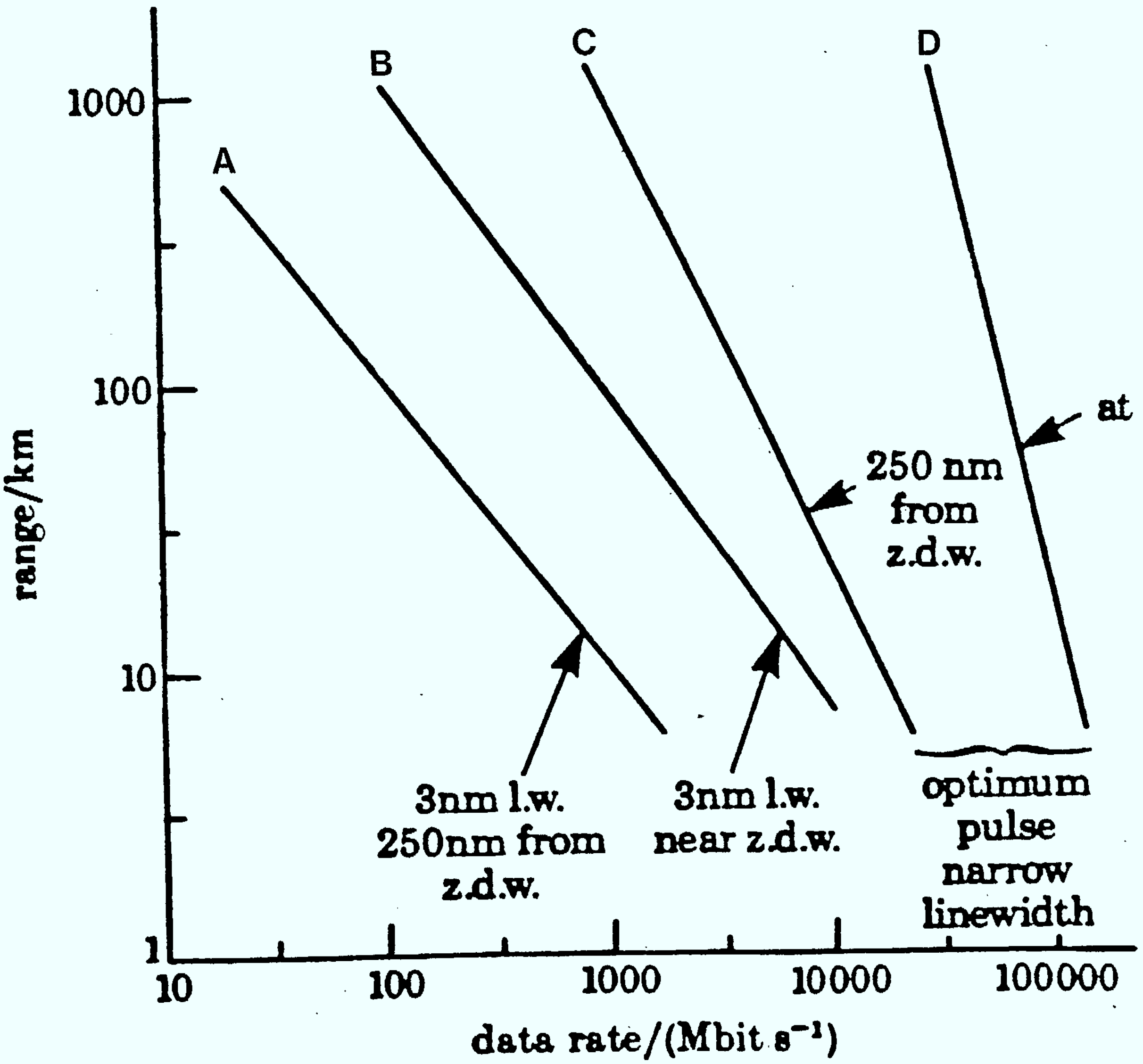
Figure 3.11 shows the possible performances of different systems, depending upon which wavelength the system is transmitting with respect to the zero dispersion wavelength. A comparison of this figure with the transmission records reported above shows that the performance of today's systems falls into that shown by line B. With improvement in linewidth and dispersion, systems will be able to do much better as shown by lines C and D.

The above discussion concentrates on telephone systems. Their capabilities are mainly judged by their bit rates and their repeaterless distances. Another important area that must be considered is the local area network. LAN aims at bringing into homes and businesses wideband integrated services, including voice, video and data. In addition to ordinary telephone services, the system could deliver CATV, picture phone, teleconferencing, and interactive information services, including electronic shopping and banking.

In the past few years LAN has not advanced according to initial expectations. The situation is rather complex. From the

FIGURE 3.11

POSSIBLE PERFORMANCE CURVES OF FIBERS



l.w. = source linewidth

z.d.w. = zero dispersion wavelength

economics point of view, the high price of connectors has a large deterring effect. Because a fiber optic connector costs hundreds of dollars, copper wire systems can be very competitive.

A more fundamental problem is that it is not yet clear what services the customers want, and how much they would be willing to pay for them. However, the kind and the quantity of services required will influence the type of network and consequently the prices to be paid for the services.

Two main types of systems have been proposed, the new optical "star" network and the old coaxial type "tree" network. The star network, with its extremely high capability, has great future potential for expansion and wideband interactive services. However, it is expensive and does not use the technology to the fullest. The tree network is an elegant system for modest requirements. It is not suitable for wideband interactive video services. It is also difficult to provide high definition or digital TV services.

In the U.S., the fiber and computer manufacturers cannot even decide on the size of the fiber to be used for LAN. Computer companies like DEC, Sperry Corp., and Hewlett-Packard are favouring the use of 100/140 micron fiber. They argue that more power can be delivered into a larger fiber; it is easier to connect and the splicing loss is less. These companies are supposed to have developed LAN systems. They are satisfied with the off-the-shelf technology connected with these larger fibers, and their performances. If the 100/140 micron fiber is adopted, they could implement their LAN systems quickly. Corning Glass

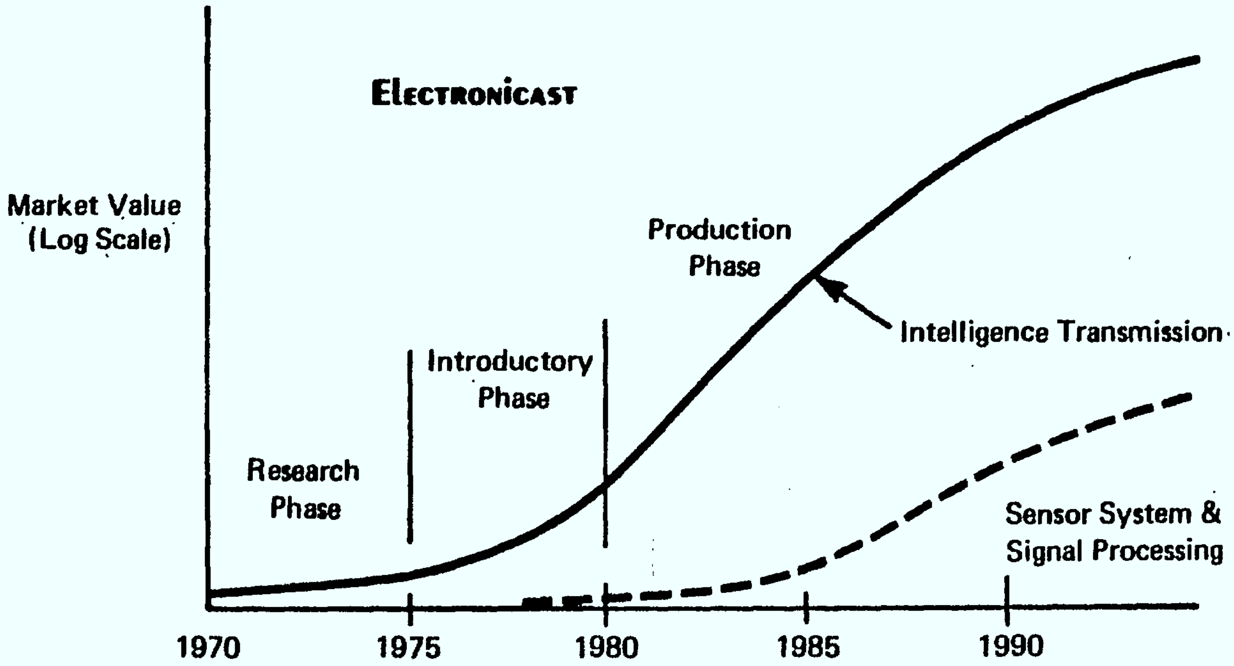
Works and AT&T are advocating the 85/125 and 62.5/125 micron fibers respectively. They say that signals can be sent through them over longer distances and that they are also cheaper. A task group, the X3T9.5, an ANSI subgroup, has been formed to meet in May, 1984, to try resolving this conflict. If successful, it will surely help in advancing the use of LAN's.

According to Kessler Marketing Intelligence, the market of LAN for 1984 will remain quite small at less than $5 million. ? Nevertheless there will be some competition among major suppliers to position themselves for the future.

4 WORLDWIDE FIBER OPTIC ACTIVITIES

In the early seventies, fiber optics was mainly a laboratory curiosity. At times, there were great concerns over its practicality. Trial systems were tested in the late seventies and they proved to be very successful. Figure 4.1 is a qualitative forecast made by the Electronicast Corporation. It shows that fiber optics is now going through a rapidly increasing production phase. Associated with these will be the emergence of some spin-off technologies. Among them will be optical sensing and signal processing, both of which are shown in the figure.

FIGURE 4-1
FIBER OPTIC COMPONENT MARKET TRENDS



4.1 ACTIVITIES BY COMPONENTS

Table 4.1 shows the worldwide fiber optic component market. The market is expected to expand by much more than ten-fold by the end of this decacde. Although the U.S. may manage to increase slightly its relative share in the production, Japan stands to gain the most in terms of trade balance. Europe and the rest of the world will consume much more than they will produce.

In terms of the areas of applications, the relative portions taken up by telecommunications and the government/military will remain essentially constant (Figure 4.2). Usage in office and computers, however, is expected to double its relative share. In terms of present-day dollars, that area is expected to change from $6 million to $176 million, an increase of nearly 30 times.

In a fiber optic system, the three major groups of components are:

(1) fibers and cables,

(2) transmitters and receivers,

(3) connectors and couplers.

A market forecast of these components, according to Kessler Marketing Intelligence, and modified for our purposes, is shown in Table 4.2 for the years 1984 to 1989. Figure 4.3 shows graphically the situations in 1984 and 1989. The forecast indicates that the immediate increases in transmitters, receivers, connectors and couplers in these two or three years will be less

TABLE 4.1

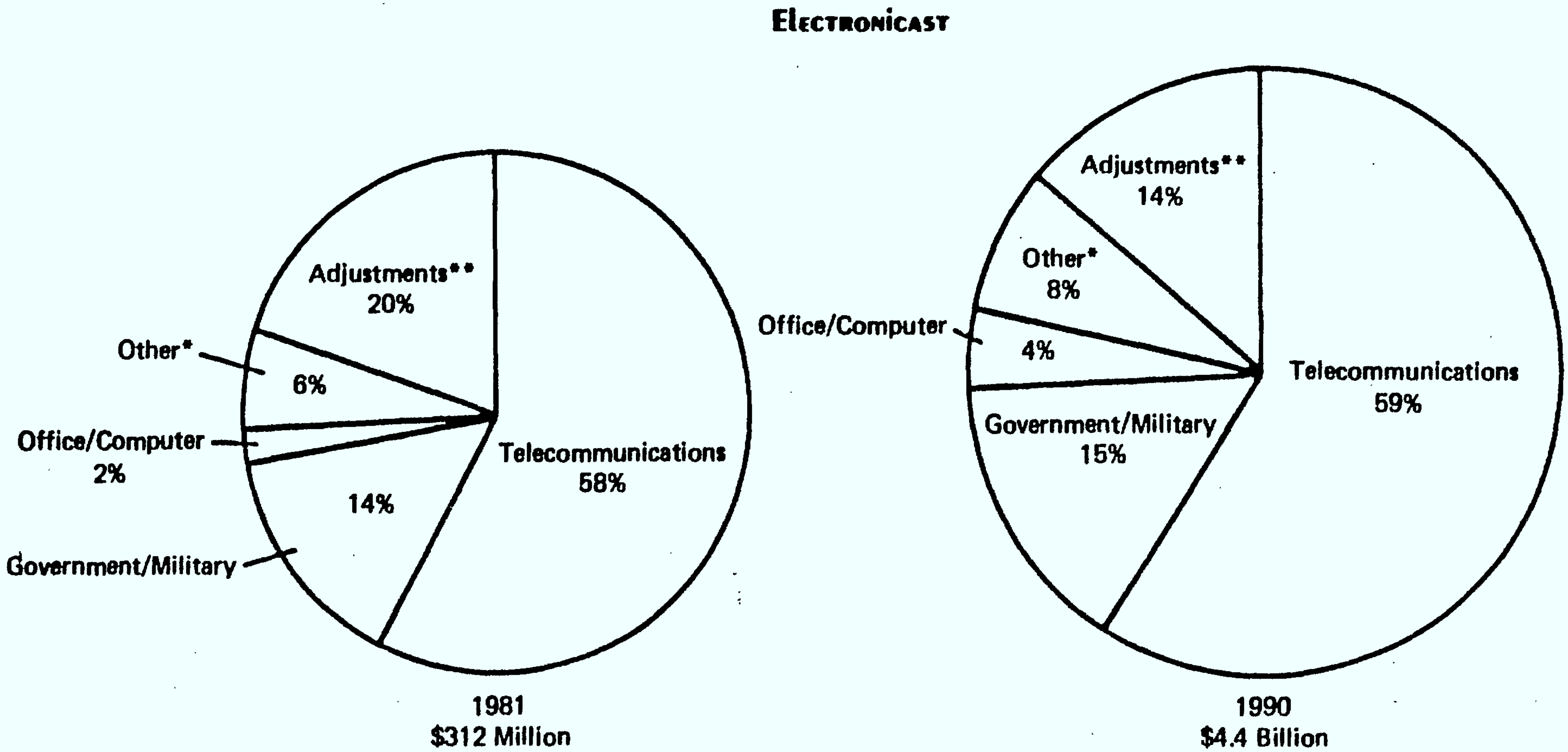
WORLDWIDE FIBER OPTIC COMPONENTS

ELECTRONICAST

	1981			1986			1990		
	Prodn.	Cons.	TB*	Prodn.	Cons.	TB	Prodn.	Cons.	TB
USA	158	153	5	1041	990	51	2309	2218	91
Japan	80	71	9	515	413	102	1121	878	243
Europe	74	73	1	461	480	(19)	952	1015	(63)
R.O.W.	0	15	(15)	5	139	(134)	14	285	(271)
TOTAL	312	312	00	2022	2022	00	4396	4396	00

*Trade Balance (Exports minus Imports)

FIGURE 4.2
WORLDWIDE FIBER OPTIC COMPONENT APPLICATIONS



* Instrument Systems, Industrial Control, CATV and Miscellaneous

**Trade Balance, Inventory Change, R&D Usage and other Nonproduction Uses

TABLE 4.2

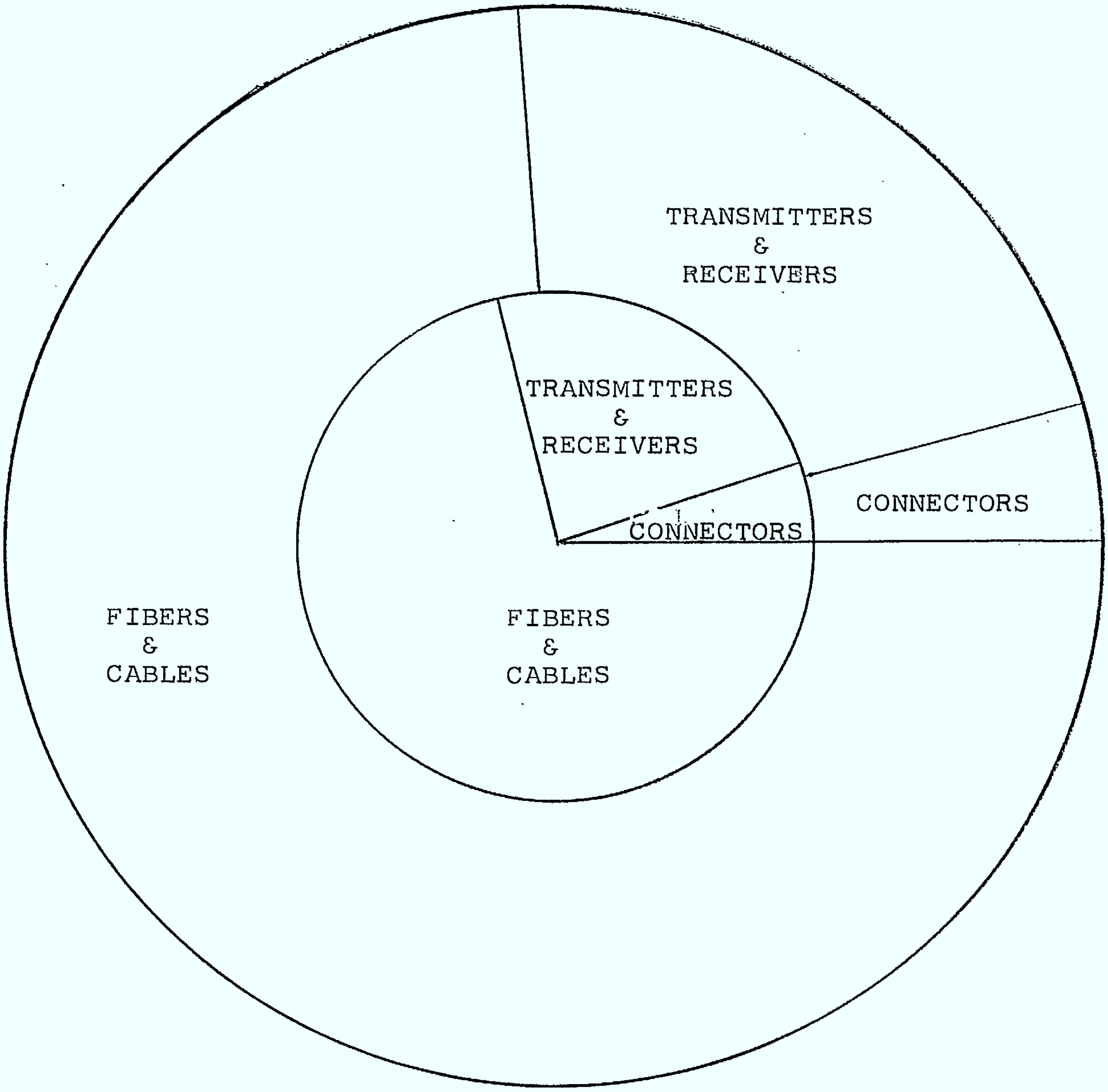
WORLD WIDE MARKET BY COMPONENT
(in millions of Canadian dollars)

	1984	Δ	1985	Δ	1986	Δ	1987	Δ	1988	Δ	1989
Fibers & Cables	755	41	1094	37	1498	33	1987	30	2587	24	3216
Transmitters & Receivers	257	33	342	31	448	34	599	24	741	28	950
Connectors & Couplers	55	33	73	30	95	22	116	26	146	25	182
Total	1087	39	1509	35	2041	32	2702	29	3474	25	4348

Note: Δ = percentage change

FIGURE 4.3

WORLD MARKET FORECAST

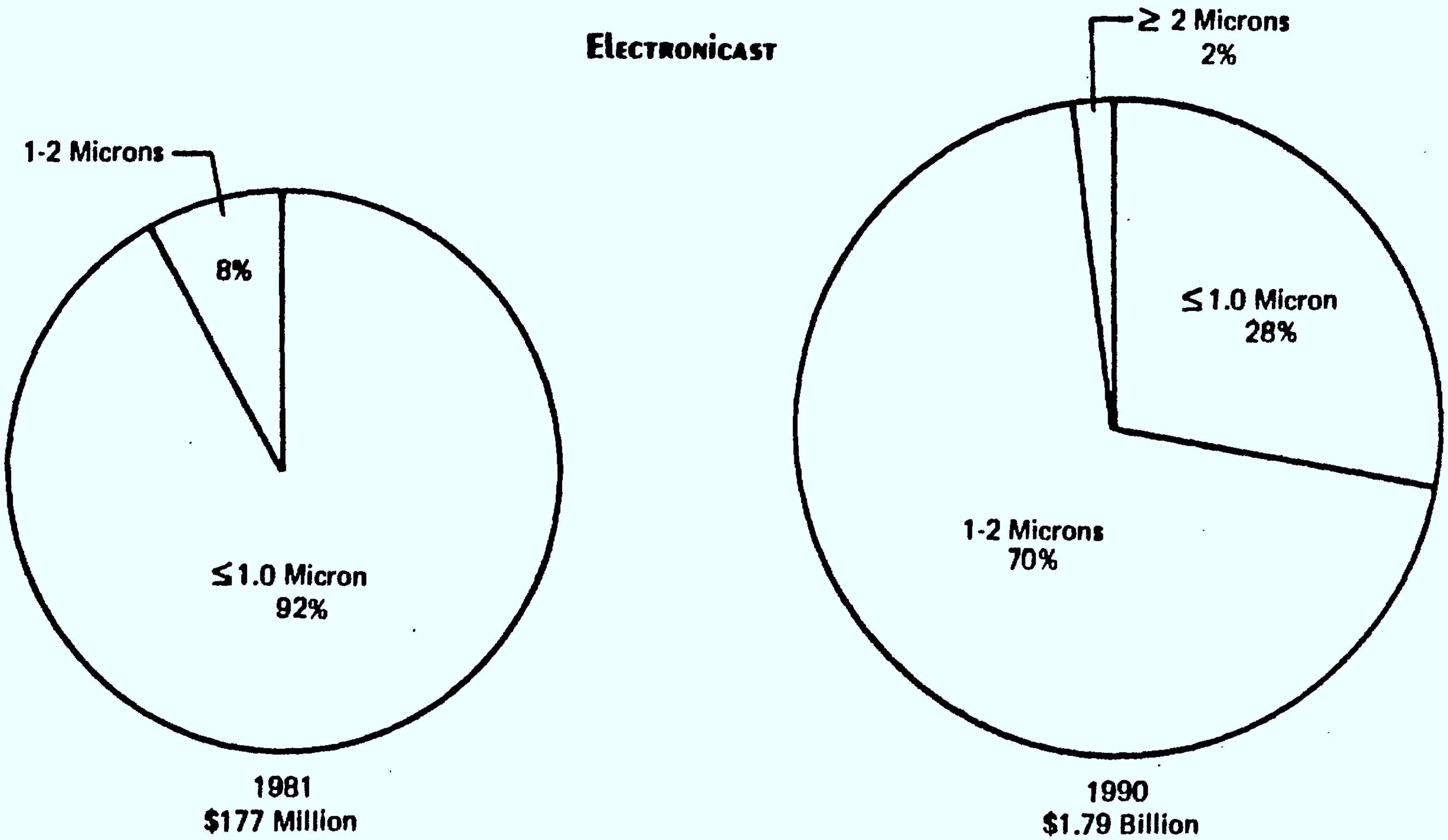


Inner Circle = 1984 (Canadian $1.1 billion)
Outer Circle = 1989 (Canadian $4.4 billion).

than the increases in fibers and cables. The main reasons are twofold. The first reason is due to the various prices. The prices of fibers and cables have dramatically decreased in the past few years. In fact, some companies had even sold below cost in an attempt to gain a market. Thus, the prices of fibers and cables will not decrease very significantly in the near future. On the other hand, the prices of transmitters, receivers, connectors and couplers have substantially remained high. It is expected that they will soon experience a major slide. The second reason is due to the qualities of the fibers. The attenuation in fibers has been drastically reduced. This is further helped by going from the short (between 700 and 1000 nm) wavelengths to the long (between 1100 and 1600 nm) wavelengths. Figure 4.4 is a prediction made by Electronicast on the shift from short wavelength to long wavelength. It shows clearly the predominance of the 1000 to 2000 nm region and the slow emergence of longer wavelengths in the future. In fact, judging from all the changes that have taken place since that forecast was made, the portion taken up by the less than 1000 nm region in 1990 should be decreased again by a good number of percentage points. In going to longer wavelengths, the losses are greatly reduced. Changing from multimode to single-mode fibers, the problem of dispersion is much less serious. Fiber optic link can now go much further before repeaters become necessary. This will have the effect of reducing the markets for transmitters, receivers, connectors and couplers.

On the other hand, as fiber optics becomes more and more

FIGURE 4.4
WAVELENGTH TREND, FIBER OPTIC ACTIVE COMPONENTS*, WORLDWIDE



*Transmitters, Receivers and Repeaters

popular, short and medium length systems will increase rapidly. A major effect of this will be an increase in the market for transmitters, receivers, connectors and couplers. Another factor that should be considered is the influence of wavelength division multiplexing. With the very rapid increase in demand for information transmission, the transmission bit rate may soon become a limiting factor. One way to ease the problem will be to use wavelength division multiplexing. WDM will reduce the need of fibers, and the number of terminals. However, it will increase the cost of an individual terminal. So the effects of WDM on the markets of transmitters, receivers, connectors and couplers will depend on the popularity of WDM, and on its price relative to other devices.

4.2 ACTIVITIES BY COUNTRY

4.2.1 INTERNATIONAL UNDERESEA LINKS

In this age of information exchange, the transmission of information is very much an international matter. The world's first international undersea fiber optic telecommunication cable will go into operation in late 1985, linking Britain and Belgium. The cost will be shared by British Telecom International, Belgium PTT, West German Bundespost, and Dutch PTT. The largest investor will be BTI which will own 50%.

Standard Telephones and Cable, an affiliate of ITT, will supply the 122 km of cable and the associated electronics, at a price of $10.15 million. The cable will be laid in the spring of 1985 by British Telecom's Cableship Alert.

The system will be capable of carrying nearly 12,000 phone calls simultaneously, doubling the existing undersea capacity between Britain and Northern Europe. The cable will carry 3 pairs of optical fibers, each operating at 280 Mb/s, providing a capacity of 3840 sixty-four Kb/s circuits. The system will use the 1300 nm wavelength, single-mode transmission, and require 3 submerged repeaters, installed at 30 km intervals.

The largest and most ambitious fiber optic system being planned is the trans-Atlantic link (TAT-8). This system will be owned by a consortium of 29 communication administrations and companies.

The route agreed to by the consortium's owners will link up Tuckerton, New Jersey, with Widemouth, England, and Penmarch, France. By this agreement, the Consortium had rejected spurs to

Canada, Spain and Portugal. However, according to documents filed with FCC by AT&T, they also agreed that the Construction and Maintenace Agreement would provide for the possibility to modify the bident configuration and turn it into a trident configuration, i.e. an addition of a branch landing in Spain; the modification could be done at any time, but it would be subject to the agreement of all the co-owners of the system.

The Tuckerton-Widemouth-Penmarch system will cost $355 million. An additional link to Coneil, Spain would cost another $32.4 million.

AT&T will receive $250 million for installing 5034 km from Tuckerton to a branching point on the European Continental Shelf. Standard Telephone & Cables Ltd., based in the United Kingdom and 35% owned by ITT, will continue the link for 446 km to Widemouth for a price of $52 million. Submarcom, a French group representing CIT Alcatel and Cable de Lyons, will receive $33 million to connect another branch of 267 km to Penmarch. AT&T is also charged to oversee the system-wide compatibility.

Shore-end equipment is to be in place by 1986, with deep-sea fiber cable installation scheduled to begin in 1987. The system is set to be operational by June 1988.

The AT&T section will contain three fiber pairs, one pair connected to each of the British and French branches, with a spare pair for redundancy. The fiber will be manufactured by AT&T Western Electric at the Norcross, Georgia, facility. It will be cabled by Simplex Wire & Cable Co., a subsidiary of Tyco Labs, which will supply 3000 miles of cable for about $40 million.

Western Electric 1300 nm InGaAsP laser diode transmitters will be used. Repeaters and other electronics will be made by Western Electric at locations in Clark in New Jersey, Reading in Pennsylvania, and Merrimack Valley in Massachusettes. Repeater spacings will be at least 21 nautical miles. The total number of repeaters used is expected to be between 125 and 175, each consisting of a regenerator for each of the 6 fibers.

The AT&T system will be a single-mode system, with repeater spacings of about 53 km. It will transmit at 560 Mb/s. Each of the European branches will carry half that capacity with 4000 64-kilobit channels. Digital speech interpolation electronics will allow the AT&T link to carry 40,000 two-way conversation channels.

When the TAT-8 system is built and operating, AT&T will own 37% of the capacity, paying $123 million for the right. British Telecom International will own 16% of the capacity, paying $51.8 million for the right. The French Telecommunications Administration will own 10% of the capacity, paying $33 million for the right. The West German Bundespost will own 7% of the system, while the rest of the capacity will be shared by the other members of the 29-body consortium.

As noted above, an important but still unresolved question is whether the TAT-8 system should have a branch to Spain. The problem has been compounded by the fact that plans now call for a trans-Atlantic TAT-9 hook-up four years later which would go from North America directly to Spain. Tentative descision plans to request tenders for the fibers in the first quarter of 1988. A final descision will depend upon future demands and the evolution of fiber optics.

4.2.2 BRITAIN

By far the largest fiber optic customer in Britain is British Telecom (BT). It is committed to replace all long-haul trunking coaxial cable with fiber optic cable and microwave radio relay, beginning this year. To do this, BT will need over 20 thousand kilometers of fiber a year. At the same time, fiber optics will penetrate into junction cable systems. This will require 30 to 60 thousand kilometers of fiber a year. As in the United States, BT's subscriber loops are often buried in ducts. Because of conjestion, the cost in digging to bury new cables, and the favourable pricing of fiber optic cables, this area holds enormous potential for fiber optic systems. As much as 100 thousand kilometers may be required to satisfy this need.

In 1979, BT issued its first fiber optic system contracts, valued at $12 million for 15 routes. The suppliers were Standard Telephone & Cables, GEC and Telephone Cables Ltd. In 1981, BT issued a second contract valued at $44 million for 65 routes. In 1982, BT issued to a consortium formed by BICC, Plessey and Corning contracts valued at $15 million to cable 28 fiber optic systems. This included the first commercial single-mode fiber system and the longest high-capacity link in the world. The former was a 52 km link between Liverpool and Preston; the latter was a 204 km, 140 Mb/s link between London and Birmingham. It issued a contract valued at $3 million to GEC for five routes, and a contract valued at $350 thousand to Standard Telephone & Cables for two routes.

Besides BT, the largest fiber optic user is the private company, Mercury Communications, which is supported by Cable & Wireless (40%), British Petroleum (40%), and Barclay's Bank (20%). It plans to install over 10 thousand kilometers of fiber (a 1300 km route with cables having eight or more fibers) to link Birmingham, Bristol and London, as well as Leeds, Liverpool and Manchester.

Broadband services are being planned by the Department of Industry, which hopes to re-cable Britain's telecommunication systems and CATV, and to provide services such as video shopping, video conferencing, security monitoring, and computerized information retrieval. This would cost over $4 billion. Because of the large bandwidth that will be required, Britain may choose single-mode fiber optic systems.

It is expected that Britain can satisfy its own fiber optic cable needs. But it may buy light sources, such as lasers and LEDs, and connector products from outside.

The suppliers in Britain are:

Fiber/Cable:	BICC
	Cable & Wireless
	Focom
	GEC Optical Fibres
	Optical Fibres
	Pilkington
	Pirelli
	Standard Telephone & Cables

	Telephone Cables Ltd.
Connector:	Belling & Lee
	Focom systems
	Hellerman-Deutsch
	Racal Microelectronics
	Standard Telephone & Cables
Transmitter/Receiver:	Belling & Lee
	Centronic
	Cossor Electronics
	GEC Telecommunications
	Optronic Fort
	Plessey
	Standard Telephone & Cables

4.2.3 FRANCE

France does not favour small systems, nor does it concentrate on long-haul trunking. It prefers linking up communities and cities with optical fibers. There have been talks in the government about replacing all coaxial cables between central offices with fiber optic cable.

One of the major undertakings was the Biarritz project. The first stage of the project provided 1500 homes with voice, video, facsimile and data communication at a cost of $100 million. The second stage would add 5000 homes to the network, at a cost of more than $350 million. The supplier of the fiber was Fibres Optiques Industries, the largest fiber production facility in Europe, which is owned by Quartz and Silice (owned by Saint-Gobain), Thomson CSF, LTT and Corning Glass. Cable was to be supplied by LTT. The system contractor was Societe Anoyme de Telephoniques.

In early 1983, a three-stage plan to fiber Paris for CATV was proposed. The first stage would have 10,000 homes and businesses in the city core served with six video channels through fiber cables. The second stage would have 130,000 clients served by 12 channels. The third stage would have 360,000 clients served by 60 channels with video services. The costs for the first, second and third stages would be respectively $14 million, $112 million and $280 million.

Several fiber optic systems were installed in Paris in 1981, 1982 and 1983, using thousands of kilometers of fiber.

The city of Montpelier had also announced a fiber optic system that would provide telephone and interactive services to 5000 clients by 1983. The city of Lille was also expected to have a fiber optic trial system followed by a major one that would use a million kilometer of fiber.

Besides in-city systems, France has a few moderate long-haul links. The first one is a 45 km 140 Mb/s system. The suppliers were GCE and CIT-Alcatel. France Telecom has a 7.5 km link between Tuileries and Phillipe in Paris. There is also a link between Dijon and Flavignerot. CIT-Alcatel will install a 100 km link between Le Mans and Angiers. There are small links in Paris and on the Cote d'Azur.

The French military is taking a serious look at fiber optics, giving out contracts to companies such as Thomson CSF's LTT and Cabletel. Fiberoptic systems are being tested on aircrafts such as the mirage 4000.

The suppliers in France are:

Fiber/Cable:	Cables de Lyon
	CIT-Alcatel
	CLTO
	Fibres Optiques Industries
	Fort Fibres
	LTT
	Quartz & Silice
	Societe Anoyme de Telecommunications

Connectors:	ATI
	CIT-Alcatel
	CLTO
	Deutsch
	Fort Fibres
	Perena
	Socapex
	Souriau
	Societe Anoyme de Telecommunications
Transmitters/Receivers:	CLTO
	Compagnie Generale d'Electricite
	Constructions Telephoniques
	Europtronique
	Fort Fibres
	LTT
	Radiall
	RTC
	Thomson CSF

4.2.4 GERMANY

Of all the western countries, Germany's government probably gives the greatest and most sustained encouragement to its fiber optic industries. In 1982, the Bundespost awarded contracts for two major programs, BIGFON (Breitbandiges Integriertes Glasfaser Fernmeldenetz) and BIGFERN, which will require 175,000 km of fiber by 1985.

BIGFON is a broadband integrated network for telephone, television, radio, facsimile and data. The subscribers in seven cities are divided very roughly into equal groups, each being served by one or two companies as follows:

AEG-Telefunken:	Dusseldorf and Hannover
Fuba:	Hannover
Krone:	Berlin
SEL/ITT:	Berlin and Stuttgart
Siemens:	Berlin and Munich
Tekade:	Hamburg and Nurnberg

The average subscriber link will be 4 km, and the maximum will be 8 km. The cost is expected to be $67.5 million. To connect the local BIGFON systems in Hamburg and Hanover, a 180 km trunk line will be installed, using graded-index long-wavelength multimode fiber operating at 140 Mb/s.

The BIGFERN uses 60-fiber cables with repeater intervals of 18 km. Installed at a cost of $225 million, it is expected to be in service in 1987.

In 1983, the German government announced that it will install one million kilometers of fiber for trunking over a ten year period, starting in 1985. This is equivalent to an annual need of 100 million meters of fiber. The Bundespost is considering replacing much of the local loop with fiber. This will require 80 to 100 million kilometers of fiber over a 25-year period.

To guarantee a good domestic supply of fibers, in December, 1982, the Bundespost approved the formation of a consortium of five German cable manufacturers: Siecor Gesellschaft fur Lichtwellenleiter (a joint company of Siemens and Corning),AEG Telefunken, Felten & Guilleaume of N.V. Philips, Kabelmetal Electro, and Standard Elektrik Lorenz. Siecor is the major shareholder. By the end of 1984, it will be able to produce 100,000 km of fiber a year. The Bundespost has promised to buy at least 100,000 km of fiber a year from 1985 to 1995. The German government has not only guaranteed that it will make heavy demands on the fiber optics but also that a very significant portion of these will be met by domestic industries.

Besides commercial use, fiber optics is also applied to military aircrafts. Messerschmitt-Boelkow-Blohm is working on systems to be used for TKF-90 figthers by 1990. Fiberoptic gyros are being researched at the University of Hamburg, AEG Telefunken, Siemens and Teldix.

The suppliers in Germany are:

Fiber/Cable:	AEG Telefunken
	Felten & Guilleaume
	Fuba
	Heraeus
	Quante Lasertechnik
	Siecor
	Standard Elektrik Lorenz
	Tekade
Connectors:	Felten & Guilleaume
	Siecor
Transmitters/Receivers:	AEG Telefunken
	Felten & Guilleaume
	Quante Lasertechnik
	Siecor
	Standard Elektrik Lorenz
	Siecor
	Tekade

4.2.5 JAPAN

The United States has been leading the world in fiber optics technology. But Japan is now challenging the U.S. for that position. Undoubtedly, this is because of its existing expertise in optics and electronics, and the timely and effective leadership and help given by its governement.

In 1972, with only two million dollars, the Ministry of International Trade and Industry (MITI) began the HI-OVIS (Highly Interactive Optical Visual Information System) program. It is an interactive video and data transmission system, installed in Higaski-Ikoma, a suburb of Osaka. This was the first fibered city. Participating companies included Fujitsu Ltd., Sumitomo Electric Co., Matsushita, and Toshiba.

The HI-OVIS offers 6 VHF and 3 UHF television channels, one interactive channel, 14 channels for video information services including videotex stored in computer memory, 2 channels for reservation services, and 4 channels for railroad schedule information.

The HI-OVIS has served as the testing ground for fiber optic components and systems evalution, validation of two-way interactive communications capability via TV, camera, microphone and keyboard, and the field trial of many communication services in education, health, news and data retrieval, security, energy monitoring and metering, and video shopping. HI-OVIS had 350 subscribers in 1982, and will have 3000 in 1985, and 10,000 in 1987.

Although the system has been very successful, and is being upgraded, it is believed that the government is now making plans to remove it, because it has already served its purpose as a very fruitful testing ground.

The center of the fiber optics work at the Nippon Telegraph & Telephone Public Corporation is its Integrated Network System. This fully digitized fiber optic system will provide customers with voice, video, facsimile, and data services. By 1987, the network is expected to cover all prefectural capitals in Japan. By 1995, all of Japan will be connected.

In 1983, International Cable Network, Tokyo Cable Network, and Tokyo Railway/Seibu Cablevision applied to the Ministry of Posts and Telecommunications for permission to construct fiber optic CATV systems developed by NTT. Much increase in this area is expected in the future.

Hitachi is selling its Sigmanet in Japan and in the U.S.. It is a local area network, transmitting at 32 Mb/s, with a ring topology to interconnect Hitachi's X2 packet switch, digital PBX's, computers, telephones, and facsimile machines.

Japan is potentially very strong in integrated circuits. Nine companies are working under a $79 million government program on integrated circuits. In addition, Hitachi, Mitsubishi, NEC, Fujitsu, Toshiba, Matsushita, Sharp, Sony, Sanyo, Sumitomo, Anritsu, and OKI are developing LEDs and laser.

Nearly all of the important work on wavelength division multiplexing has been done in Japan. Such a technique will allow full duplex transmission, will reduce the costs of subscriber loop systems, and will increase the flexibility.

Japan is going over to single-mode fiber systems. In 1980, NTT bagan a field trial with single-mode fibers transmitting at 400 Mb/s at 1300 nm wavelength and 10 to 20 km repeater spacings. The longest single-mode system is expected to be completed in 1984, linking Sapporo in the North with Fukuda in the South.

Japan is threatening to dominate the world in fiber production. Its two principal companies have undergone significant expansions. In 1982, Sumitomo Electric Industries completed a $12 million expansion in Yokohoma. The company is now capable of producing 250,000 km of fiber annually. Furukawa Electric Industries built a $8 million fiber optic cabling plant in Ichikara, Chiba Prefecture, that can produce from 2000 to 6000 km a month. It is estimated that Japan has the fiber production capacity to meet the combined demand in the U.S. and in Japan. Technologically, Japan has very significant achievements in producing fibers. The vapor-phase axial deposition process, invented and developed by NTT has produced fibers with the lowest attenuation and the largest bandwidth. Its polarization-maintaining fibers and low loss plastic fibers, with 29 dB/km at 650 and 680 nm, are also very promising.

The suppliers in Japan are:

Fiber/Cable:	Dainichi-Nippon
	Fujikura
	Furukawa

	Hitachi
	Mitsubishi Rayon
	NSG
	Showa Electric
	Sumitomo
Connectors:	Aoi Sansho
	NEC-Electron
	Sumitomo
Transmitters/Receivers:	Dainchi-Nippon
	Fukotsi
	Hitachi
	Matsushita
	NEC
	Sumitomo
	Toshiba

4.2.6 UNITED STATES

As in all other countries, fiber optic activities in the United States are dominated by the telephone companies (58% of the whole market in 1982). However, there are also other important sectors, namely military (23%) and computer interconnect (15%). The utilities are also beginning to accept fiber optics.

The biggest customers are the Bell operating companies. MCI Telecommunications could seriously compete with the Bell System through its expansive fiber optic routes. During 1984 to 1986, it expects to invest more than $1 billion in fiber optics. In a few years, GTE's acquisition of Southern Pacific's SPRINT system could also provide similar competition.

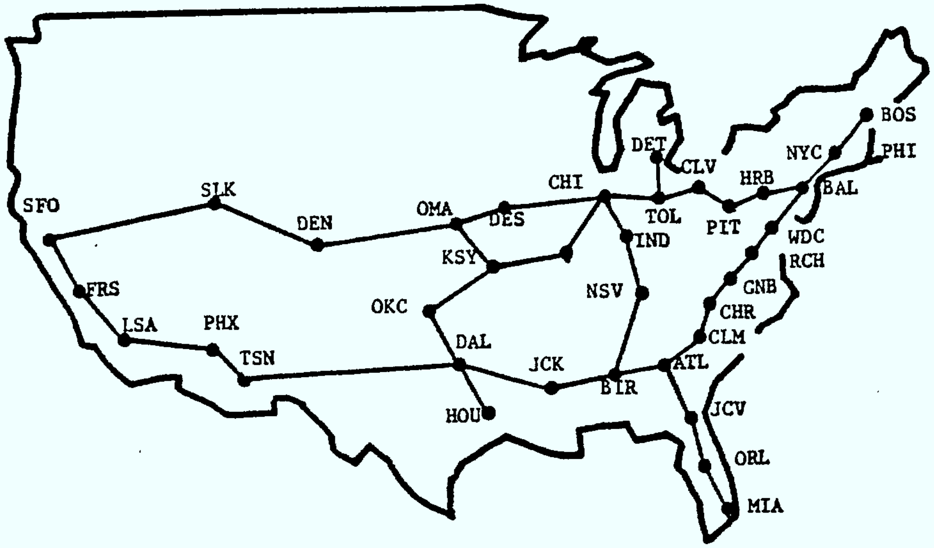
Corning Glass Works was one of the pioneers in fiber optics that had initiated the rapid growth of fiber optics. Major development and production work has been done by Western Electric, which has always been helped by its preferred customer, the Bell companies. As the latter expand over the decade, so will the fiber activities in Western Electric.

There are some independent telephone companies which have accepted fiber optics: Centel, Contel, GTE, and United. In 1982, the telephone common carriers installed 120,000 km of fibers, accounting for $72 million of the market.

Figure 4.5 shows a Bell future plan of fiber optic trunks in the U.S. The major hubs will be Chicago and Dallas. In the northeast corridor, AT&T has used multi-ribbon cable containing

FIGURE 4.5

POTENTIAL LONG-HAUL FIBER OPTIC LINKS OF BELL SYSTEM



more than 72,000 km of fiber. Pacific Bell has used 46,000 km of fiber in its San Francisco/Los Angeles North-South Project. By the end of 1984, another 14,000 km of fiber will have been added to the system. In addition to these, in 1983, the Bell companies have cutover more than 300 subscriber loop carrier systems; AT&T awarded Western Electric a contract for five trunk lines in the eastern corridor.

By the middle of 1983, GTE and Continental Telephone had each installed about 30 systems, while United Telecommunications had 14. Centel had 8, and a few small telephone companies had a total of about two dozen.

There are four major specialized common carriers in the U.S.: MCI Telecommunications, Southern Pacific's SPRINT system, Western Union, and Satellite Business Systems. MCI announced in January 1983 that it would install 240,000 km of fiber along 6800 km of railroad rights-of-way obtained from Amtrak and CSX Corporation. The fiber will be of single-mode type, 96,000 km from Northern Telecom and 144,000 km from Siecor. MCI will also install feeder systems, requiring another 50,000 km of multi-mode fiber. The whole system is expected to cutover by 1988.

GTE is expected to spend $8 to $9 billion on SPRINT over the next ten years, with fiber optic systems accounting for more than $100 million through 1989. Such systems are expected to be installed in San Francisco, San Antonio, Dallas, St. Louis and New York/New Jersey. Trunk lines will link New York-Atlanta, Atlanta-New Orleans, New Orleans-El Paso, El Paso-San Diego, San Diego-San Francisco, Boston-New York, Arkron-Chicage, and

Chicago-St. Louis-Dallas.

In 1983, the U.S. military spent $41 million on fiber optics --- $11 million on basic research, and $30 million on applied research and production. A major ongoing contract is the $20 million fiber optic transmission longhaul system, awarded in June, 1982, to ITT's Defence Communications Division and to Standard Telecommunications Laboratories. In April, 1984, ITT received a $2.9 million incremental funding contract to continue the engineering and developmental work of this project. In August, 1982, a $5.2 million tactical generic cable replacement contract was awarded to GTE and TRW. In 1983, the Navy spent $6 million on fiber optic sensor systems, and again about the same amount in 1984. It is expected that the U.S. military will continue to have significant expenditures in fiber optics, especially in fiber optic links between radar control stations and radar antenna. A military fiber optic market forecast is shown in Table 4.3. The number of military fiber optic programs jumped from 38 in 1982 to 117 in 1983, while the number of installed systems increased from 10 to 19, developmental systems increased from 12 to 27, and initiated or planned systems rose from 16 to 61.

The Utilities Telecommunications Council has been encouraging the utilities to use fiber optics since 1983. Most recently, they began using it to overcome environmental difficulties. So far, there are twenty-two utilities that have fiber optic systems installed or planned to be installed. This trend is expected to continue.

American Electric Power, with headquarters in Canton, Ohio,

TABLE 4.3

U.S. MILITARY FIBER OPTIC MARKET

(in millions of Canadian dollars)

1984	1985	1986	1987	1988	1989
150	200	280	250	460	550

this year will construct a trial installation 10-30 km long that will use composite static cable (ground wire with integral fiber cable) and single-mode fiber. They may also employ WDM.

Computer interconnection includes fiber optic transmitters, receivers, fiber, cable, and connectors between main-frame, mini- and micro-computers, computer terminals, and peripherals in the commercial and industrial sectors. The market forecast in this area is shown in Table 4.4

The market for video links are relatively smaller. The forecast is shown in Table 4.5.

There are over 40 suppliers of components for fiber optic data links (excluding fiber and cable suppliers for the whole fiber industry). They are listed in Table 4.6. The major suppliers are: Hewlett-Packard, Burr-Brown, Honeywell, Motorola, and Belden.

The suppliers in the U.S. are:

Fiber/Cable:	Anaconda-Ericsson
	Belden
	Corning
	Fiberguide Ind.
	General Cable
	ITT
	Mohawk
	Pirelli
	Siecor
	SpecTran
	Times Fiber Com.
	Valtec

	Western Electric
Connectors:	AMP
	Amphenol
	Deutsch
	GTE Lendurt
	Hewlett-Packard
	Hughes
	ITT-Cannon
	OFTI
	Thomas & Betts
	Trompeter
	TRW Cinch
	Western Electric
	Winchester
Transmitters/Receivers:	Canoga Data Systems
	Codenoll
	Collins
	General Optronics
	GTE Lenkurt
	Harris
	Hewlett Packard
	Honeywell
	ITT
	Laserton
	Motorola
	OIS
	Telecom Systems
	Western Electric

TABLE 4.4

COMPUTER INTERCONNECTION

(in millions of Canadian dollars)

1984	1985	1986	1987	1988	1989
90	150	220	290	400	520

TABLE 4.6

FIBER OPTIC VIDEO LINKS

(in millions of Canadian dollars)

1984	1985	1986	1987	1988	1989
50	60	80	90	100	110

TABLE 4.6

SUPPLIERS OF COMPONENTS FOR FIBER OPTIC COMPUTER INTERCONNECT SYSTEMS

AETNA TELECOMM.	AMERICAN PHOTONICS	AMP
ARTEL	AUGAT	BELDEN
BURR-BROWN	CANOGA	CODENOLL
CHESAPEAKE LGT. SCI.	FIBERCOM	FIBERLAN
FIBRONICS	GEN. FIBEROPTICS	FOUNDATION
FUJITSU	GANDALF	HARRIS
HEWLETT-PACKARD	HONEYWELL	ITT
LeCROY	3M	MANAGE
M/A-COM-DCC	MATH	MERET
MOTOROLA	NATIONAL SEMI.	NEC
NSG AMERICA	OPTELECOM	OPTICAL COMMUN.
TELCO SYSTEMS	OIS	PHALO
RCA	ROLM	SIEMENS
SUMITOMO	TI	VERSATRON

5 CANADIAN TELEPHONE COMPANIES

5.1 BRITISH COLUMBIA TELEPHONE

The British Columbia Telephone has 12 fiber optic systems in service. One is being installed and is expected to be functioning in a few months. Two are being planned. All of the early systems transmit with multimode fibers at a bit rate of 45 Mb/s at 840 nm. Nearly all those systems have route lengths of less than 10 km, probably because the unrepeated lengths for those systems were about 10 km. Notable systems with repeaters are the two between Vancouver and New Westminster. One has a route length of 27 km and the other of 22 km. They both transmit at a bit rate of 45 Mb/s and use a wavelength of 840 nm. At a longer wavelength, 1300 nm, the repeaterless length could be increased to about 50 km or more. So, again, BC Tel has managed not to use repeaters for routes using this long wavelength.

In all, BC Tel has a total route length of 200 km of fiber optic transimssion lines in service. The amount of fibers in these systems is over 2 million meters. Table 5.1 gives some details of each of the systems.

There are two systems being planned that will be the most advanced and the longest of all the fiber optic systems BC Tel has ever undertaken. The first system will connect Nanaimo and Parksville with a total route length of about 44 km and the second system will connect Mission and Agassiz with a total route length of about 49 km. The cable of the latter system will have 8 fibers, while that of the former systems will have 12 fibers for the Nanaimo-Wellington section, and 8 fibers for the

TABLE 5.1

BC TEL FIBER OPTIC LINKS

System	Route Length	No. Fibres	Type	Bit Rate	Wave-length	Type
Vancouver (Hemlock-Cypress)	7.4	2	Multi-mode	45 mb/s	840	Trial
Victoria to Smith Hill (Radio)	3.3	12	"	"	"	WLEL
Vancouver to New Westminster I	27	12	"	"	"	Trunk/ WLEL
Vancouver (Mutual-Regent)	4.3	24	"	"	"	"
Vancouver- New Westminster II	22	24/36	"	"	"	"
Campbell River (Radio)	2.0	24	"	"	"	WLEL
Penticton radio	6	12	"	"	"	"
Cranbrook Radio	"	18	"	"	"	"
Invermere Radio	9	12	"	"	"	"
Newton to New Westminster	16.4	"	"	"	1300	Trunk
Victoria-Keating	23	"	"	"	"	"
Newton-Steveston	33	"	"	"	"	"
Haney-Mission	30	"	"	45	"	"
Nanaimo-Parksville	44	8/12	Single Mode	135	"	"
Mission-Agassiz	49	8	"	"	"	"

Note: WLEL=Wire Line Entrance Link

Wellington-Nanoose-Parksville section. All cables will have single-mode fibers supplemented by 2 pairs of copper wires. Both systems will transmit with a bit rate of 135 Mb/s at 1300 nm. Although BC Tel will buy the cables and the associated electro-optic equipment, the company will install and wire the equipment, place the fiber cables, and test the system acceptance.

So far, BC Tel has used two bit rates, 45 and 135 Mb/s. If, in the future, the traffic becomes too heavy, the company intends to double or even triple the 135 Mb/s bit rate to satisfy the requirements.

5.2 ALBERTA GOVERNMENT TELEPHONE

For the past several years, Alberta Government Telephone (AGT) has embarked on a major program of installing fiber optic transmission systems as an integral part of its network. This represents a major committtment to the utilization of state-of-the art technology.

AGT utilizes fiber optic systems in the following applications:

(1) Metropolitan interexchange trunking

(2) Toll connect and intertoll trunking

(3) Digital entrance links (to radio systems)

As of September, 1983, AGT has the following fiber optic transmission systems:

Number of T3 channels:	75
Number of T3C channels:	7 (14 T3)
Number of T4 channels:	3 (18 T3)
Total:	107 T3

The Alberta Government Telephone has 366 km of fiber cable, containing 9512 km of fiber. Table 5.2 gives the essential details of the systems. As usual, early systems transmit with the

TABLE 5.2

ALBERTA GOVERNMENT TELEPHONES FIBER OPTIC TELEPHONE SYSTEMS

Route Number	Cable Route	Total Length	Repeater Spacing	Rate	Supplier	Window	Attenuation	Number of Fibers
F01	Edmonton-Nisku	29.5	15	T3 T3C	Phillips/DTL	Single	2.23	50
F02	Nisku-Leduc	10		T3 T3C	Phillips/DTL	"	3.4	42
F03	Leduc-Kavanagh	15		T3C	Phillips/DTL	"	2.34	36
F04		13	6.5	T3	NTC	"	3.5	26
F05	SW PK RA-RE-SWPK CDO	3.7		T3	"	"	3.5	20
F06	SW PK RA-RE - Bonnie Doon	3.3		T3	"	"	3.5	12
F07-1	Calgary Main - Mt. Royal	3.3		T3	"	"	3.5	48
F07-2	Calgary Main - Mt. Royal	3.2		T3	"	Triple	3.4(850 nm)	48
F08	Capital Hill - Mt. Royal	4.8		T3	"	"	3.4(850 nm)	24
F08-1	Mt. Royal - Capital Hill	4.2		T3	"	Single	3.5	32
F09	Mt. Royal - Elbow Park	3.0		T3	"	"	3.5	30
F10	Elbow Park-Kingsland	7.2		T3	"	"	3.5	30
F11	Mt. Royal-Killarney	3.6		T3	"	"	3.5	24
F12	Main - Forest Lawn	7.6		T3	"	"	3.5	24
F13	Main - Cheadle RA-RE	50	3.2	T4	Farinon Canstar	"	6.0	12
F14	Main - Earth Station	15	7.5	T3	NTC	"	3.5	16
F15	Lethbridge-Lethbridge RA-RE	10		T3	"	"	3.5	16
F16	Calgary - Crossfield	47.4	3.2	T3	"	Double	3.0	32
F17	Airdrie-Airdrie Junction	3.5	3.2	T3	"	"	3.0	8
F18	Red Deer-Red Deer RA-RE	3.5		T3	"	Single	3.5	14
F19	Grande Prairie CDO - Grande Prairie RA-RE	3.1		T3C	Phillips/DTL	"	4.0	16

TABLE 5.2 (continued)

Route Number	Cable Route	Total Length	Repeater Spacing	Rate	Supplier	Window	Attenuation	Number of Fibers
F21	Kingsland - Mt. Royal	10.2		T3L	NTC	Triple	3.4(850 nm) 1.2(1300 nm)	24
F22	Bowness - Mt. Royal	8.5		T3L	"	"	3.4(850 nm) 1.2(1300 nm)	24
F23	Capital Hill - Manhole #1A31	8.2		T3L	"	"	0.9(1300 nm)	24
F24	Huntington Hills - Manhole # 1A31	4.5		T3L	"	"	0.9(1300 nm)	16
F25	Manhole #1A31 - Airways	4.7		T3L	"	"	0.9(1300 nm)	24
F26	Airways - Forest Lawn	12.3		T3L	"	"	0.9(1300 nm)	24

shorter wavelength of 850 nm. Recent installations utilize the 1300 nm wavelength. A few systems with triple-window fibers have been functioning with wavelength division muiltiplexing, using 850 nm and 1300 nm wavelengths.

The existing Calgary interexchange fiber optic transmission network is continually being expanded to accommodate traffic growth requirements. The ultimate expansion capabilities of the existing AGT fiber optic transmission network would involve an additional 122 T3 channels. In the future, nearly all major interexchange trunking and entrance link systems will utilize fiber optic transmission systems. The next generation of fiber optic installations will be systems involving single-mode fibers and transmitting at higher bit rates.

5.3 EDMONTON TELEPHONES

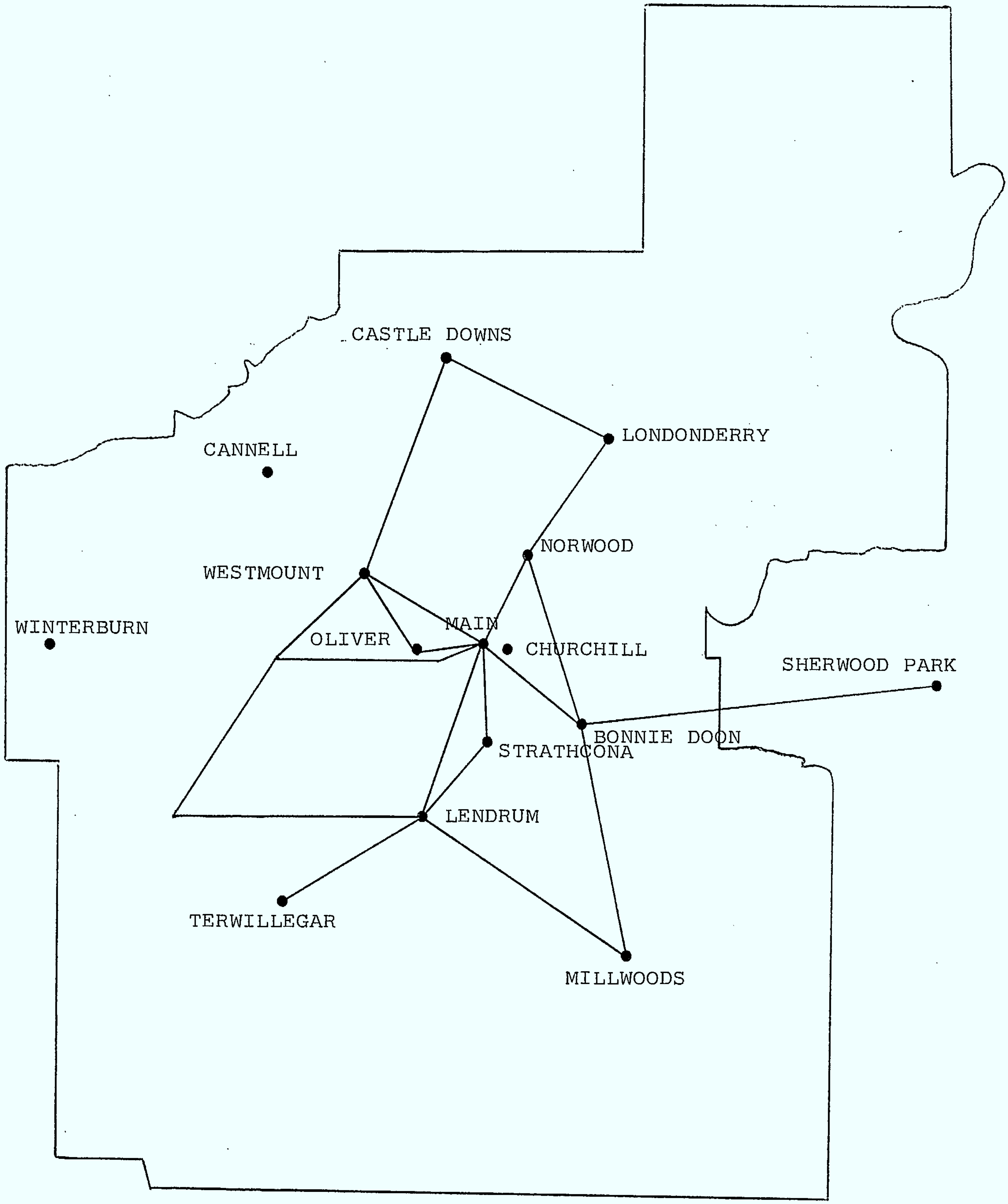
Edmonton Telephones (ET) has been involved with the engineering and installation of fiber optic and digital transmission systems since 1979.

The fiber optic transmission system is used primarily for inter-office connections. The majority of the equipment operate at the 4.5 Mb/s bit rate and at the 850 nm wavelength. There is one DS-3 rate system transmitting at the 1300 nm wavelength. By the end of 1984, the company will have installed four 135 Mb/s systems which will operate at the 1300 nm wavelength. As of April 1984, Edmonton Telephones has 76 T3 systems in operation. Thirty-three systems will be installed by the end of the year, bringing the total number of T3 systems to 109.

All cables use multimode, dual window fibers, with attenuation ranging from 2.5 to 3 dB/km at 850 nm. ET uses two cable sizes --- 12 fibers and 24 fibers. Up to 1984, ET has installed 115 km of fiber optic cables which is equal to 2362 km of fiber. Figure 5.1 shows a map of the different fiber optic links. ET is presently looking at the single-mode technology and its use within the company's network.

FIGURE 5.1

EDMONTON TELEPHONES FIBER OPTIC SYSTEMS



5.4 SASKATCHEWAN TELECOMMUNICATIONS

Saskatchewan Telecommunications has an extensive fiber optic network. Its BBN program is expected to be completed in 1984. Beyond then, there could be a limited message requirement, and a potential Telecom Canada message facility in the late eighties. However, both are as yet not defined.

Table 5.3 gives the yearly fiber placement from 1980 to 1984.

Table 5.4 gives the yearly message or protection service from 1982 to 1988 and beyond.

Table 5.5 gives the yearly video electronics addition from 1981 to 1984. It should be noted that the 135 Mb/s fiber is carrying 3 video channels. Beyond 1984, only limited video additions are expected.

Figure 5.2 is a map which shows the broadband network of Sask Tel.

TABLE 5.3

FIBRE OPTICS IN SASK TEL

FIBRE PLACEMENT

YEAR	SHEATH KM	FIBRE KM	GI/MONO	WAVELENGTH	CABLE SIZE (FIBRES) PREDOMINATE	OTHER
1980	30	360	GI	SWL	12	-
1981	865	10,740	GI	DW	12	-
1982	660	8,970	GI	DW	12	18
1983	1060	10,000	GI	DW	12	8
1984	3085	31,120				

TABLE 5.4

MESSAGE OR PROTECTION SERVICE

YEAR	BIT RATE	SWL	LWL
1982	45 Mbit	440 KM	--
1983	"	1740	480 KM
1984/1985	--	--	--
1986	45 Mbit	1520	110
1987	135 Mbit		520(mono)
1987	45 Mbit	100	150
1988 & Beyond	Mix 45/135	500 KM/year	

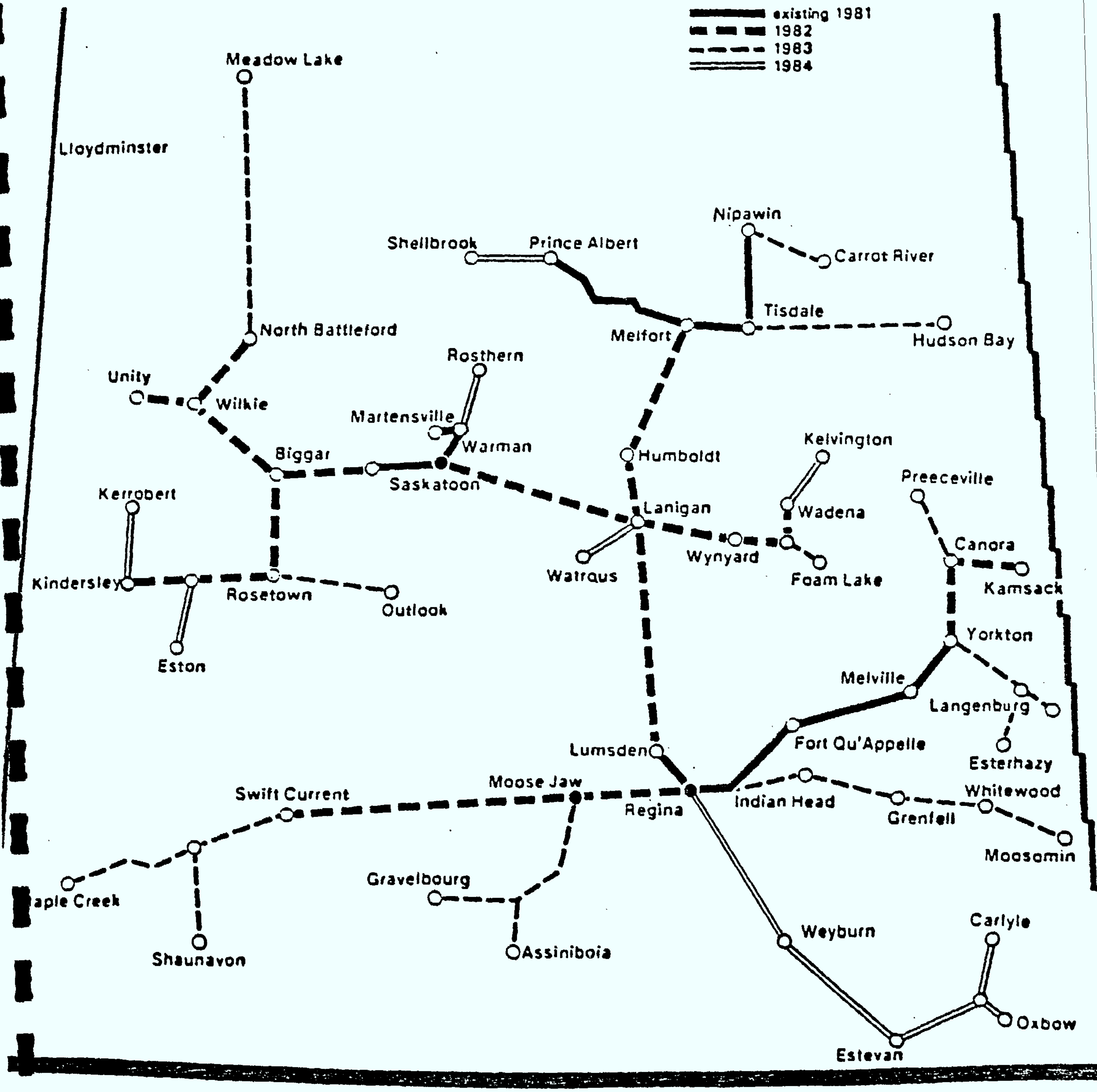
TABLE 5.5

VIDEO ELECTRONICS ADDITION

	BIT RATE	WAVELENGTH	KM (FIBRE)
1981	45 Mb	SWL	3580 KM
1982	"	"	2640 KM
1983	"	LWL	4680 KM
1984	135 Mb	LWL (MONO)	530

FIGURE 5.2

SASKATCHEWAN TELECOMMUNICATIONS BROADBAND NETWORK



5.5 MANITOBA TELEPHONE SYSTEM

The Manitoba Telephone System has two different fiber optic systems, one has a bit rate of 90 Mb/s and the other 135 Mb/s. In all, they cover a route length of over 100 km and a fiber length of more than 1000 km. Both systems use multimode fibers. Equipment was supplied by Nippon Electric Co., AEL Microtel and Northern Telecom. The fibers for the lower bit rate systems were supplied by Canstar, while those of the others were supplied by Northern Telecom.

One new system is being planned. It will tie in with the existing DRS8 digital radio at Brandon Remote on the west and with Grassmere on the east. The route length will be over 235 km. It will handle trans-Canada as well as intra-provincial traffic. This system will replace a 2GHz analog radio system. The cable to be used is expected to have 24 single-mode fibers, transmitting at 135 Mb/s, expandable to 405 Mb/s when required. The repeater spacing will be approximately 35 km.

All the above fiber optic systems carry messages and data. As yet there are no video systems.

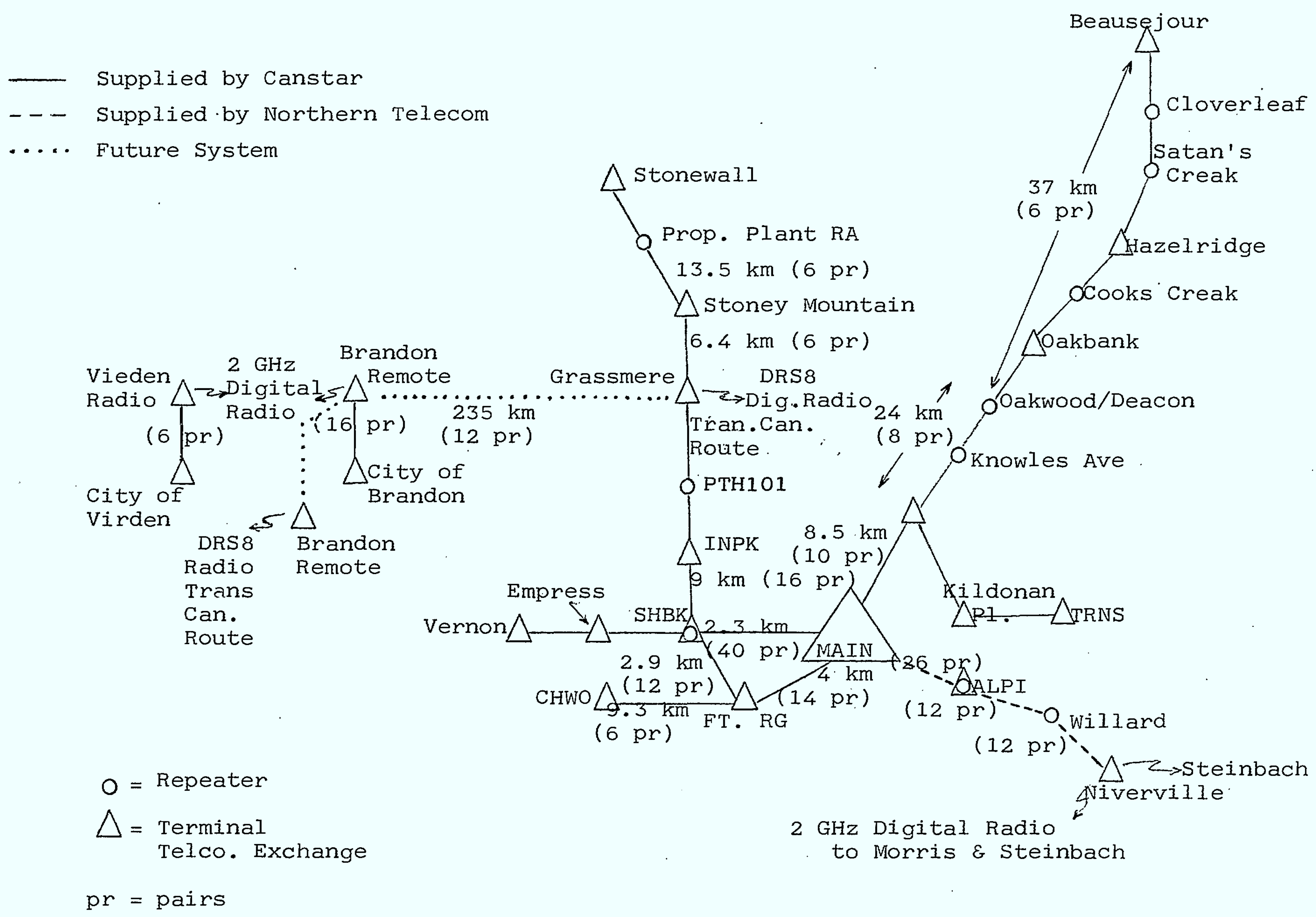
Figure 5.3 shows the locations and some details of the three systems described above.

Elie-St. Eustache Field Trial

In 1976, the Federal Department of Communications (DoC) commissioned Bell Northern Research (BNR) to carry out a system

FIGURE 5.3

MANITOBA TELEPHONE SYSTEM FIBER OPTIC LINKS



study of fiber optics for broadband communications. At about the same time, the Manitoba Telephone System proposed a rural fiber optic field trial for Elie. The result of these activities was the Elie-St. Eustache field trial program co-sponsored by the Government of Canada, the Canadian Telecommunications Carriers Association, the Manitoba Telephone System, Infomart and Northern Telecom. The design phase began in September 1979. The trial program was completed in March 1983, after an 18 month operation trial period.

The main objectives of the trial were to:

(1) gain experience in the design, implementation, operation and maintenance of a fiber optic subscriber access network;

(2) provide a test bed for new telecommunications services;

(3) determine the telecommunications and information needs of people living in rural areas;

(4) promote the development of new telecommunications products and services.

The system configuration is a star network with centralized switching as shown in Figure 5.4.

It provides to all the 150 subscribers services in:

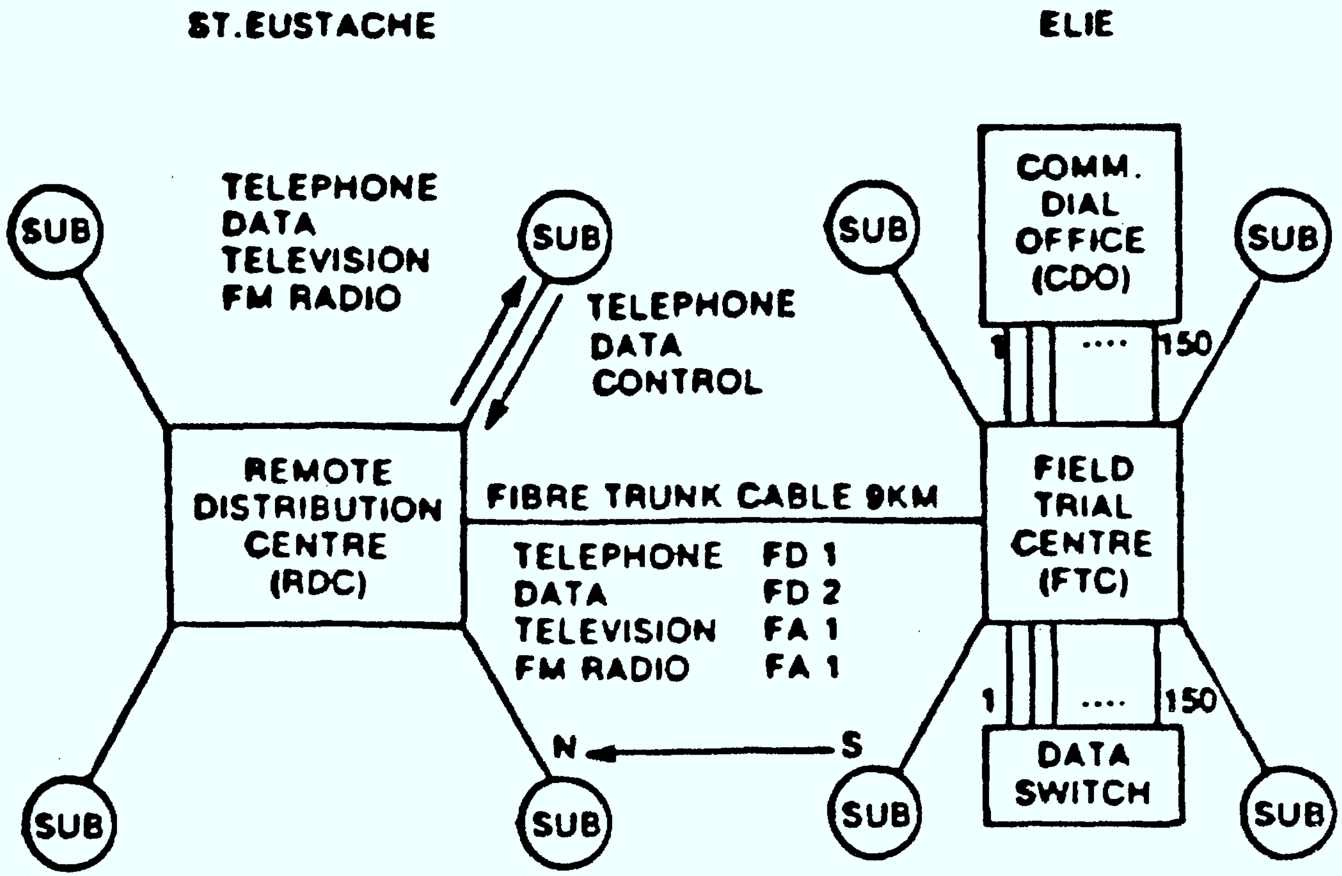
(1) telephone

(2) CATV and FM radio

(3) data

FIGURE 5.4

ELIE-ST. EUSTACHE DISTRIBUTION NETWORK



In addition, 25 subscribers have the option of receiving two TV channels simultaneously.

Voice, data and control signals are digitally transmitted. Video and FM radio signals are transmitted in analog form. There is one fiber trunk for each of the 9 video signals and one trunk for all of the 7 FM radio signals. Voice signals are transmitted at 1.544 Mb/s rate and data at 6.3 Mb/s on the trunk.

The system uses 930 nm and 830 nm wavelengths for the respective upstream and downstream operations. This is believed to be the first use of wavelength division duplexing in a telephone network.

The total amount of fiber optic cable used is 9 km for the trunk between the Field Trial Center and the Remote Distribution Center, and 75 km for the distribution plant. All the cables are non-pressurized, but have a dry-powder fill which prevents water seepage from a damage in the cable sheath. The cables are made with graded-index multimode fibers, with a numerical aperture of 0.17, an attenuation less than 4 dB/km at both 840 nm and 930 nm wavelengths. The core and cladding diameters of the fibers are 50 microns and 120 microns respectively.

The field trial has demonstrated that fiber optics technology can be used in the subscriber access plant. Present telephone plant construction methods and equipment can remain largely unchanged, with the addition of special equipment and know-how for splicing and testing optical fibers. There were essentially no major failures of the optical components affecting the operatio ns and service. The additional training required by the telephone craftspeople to install the system was minimal.

The system performance has been judged to be satisfactory. The administration has now been returned to the Manitoba Telephone System with the understanding that it will serve as a national testing ground for future technology and service trials.

5.6 BELL CANADA

Bell Canada is currently employing two basic transmitting systems --- the FD-2, operating at 6.3 Mb/s electrical (12.6 Mb/s optical), and FD-3, operating at 44.7 Mb/s electrical (47.7 mb/s optical). Both systems are used with 840 nm and 1300 nm wavelengths.

At present, these systems are supplied to local interoffice, digital entrance link and short intertoll trunk applications.

In the summer of 1983, Bell Canada announced that in the future, all links less than 70 km long would be installed with optical fiber, and that it would double its fiber links in the next two years. To date, the company has a total of 50 systems, interconnecting approximately 90 locations with 17.5 thousand kilometers of fiber. FD-3 systems account for about 65% of the total systems, and use 70% of the fiber length. The average system lengths are 18.5 km for the FD-2 and 14.0 km for the FD-3.

In the latter part of 1984, the company expects to introduce FD-135 systems, operating at a rate of 135 Mb/s and using single-mode fibers. By 1986, it plans to use optical fiber in the feeder cable portion of its distribution or loop plant, i.e. from the central office to large buildings and subdivision entrances.

The following is a very brief chronological account of fiber optics development of Bell Canda:

Early 70's:

BNR began conducting analytical research into optical fiber systems. By 1973, in cooperation with Northern Telecom's cable division laboratories, BNR developed a fiber drawing facility. In 1974, BNR began the fabrication of experimental silica using a chemical vapour deposition process.

1976:

An experimental optical fiber system trial in downtown Montreal used optical fiber cables for telephone transmission. Buried in conventional cable ducts, this trial ran successfully between two Bell Canada switching centres.

1978:

A second generation cable designed by BNR was installed as part of an entrance link to a Telesat Canada transmitter in Quebec. The cable, designed by BNR was being manufactured by Northern Telecom Canada for its FD-2 and FD-3 fiber transmission systems.

Bell Canada began its Yorkville fiber optics trial, a loop system field demonstration provided for Toronto residences.

1979:

The first commercial Bell Canada field trial installation in Weir, Quebec establishes the first satellite earth station to radio microwave link.

1980:

April

The first fiber digital entrance link technology trial designed to link a radio tower to a toll office, in Kitchener, Ontario.

June

The first FD-2 interoffice system field trial began between St. Agathe and Ste. Adele in Quebec, providing a 96 channel/system service.

December

The first FD-3 fiber digital entrance link in Ottawa was established providing a 672 channel/system service.

1981:

March

The first fiber optic trial using commercial high speed digital data began in Ontario. Two Toronto-based firms, Datacrown Inc. and Canada Systems Group (CSG) participated in this trial designed to test and evaluate fiber optic technology for computer communications operations.

Ten additional projects in various Ontaio locations commenced in order to gain experience in fiber optics transmission systems (FOTS) technology and operation.

1982:

FOTS systems were used extensively in the province of Quebec in order to centralize the toll functions and improve network reliability in the Montreal vicinity.

1983:

Cost reduced multiplex and higher capacity FOTS terminal equipment were available.

Strategic and operational benefits of FOTS had been re-assessed in detail and had compared most favourably to the existing copper based systems in terms of economics and operational benefits.

June

Bell Canada announced that all new installations of cable between switching offices, as well as short-haul long distance facilities, would be fiber optic cable. In addition, fiber optic cable would be used to reinforce, supplement and replace, as required, existing copper-based transmission facilities.

5.7 NEW BRUNSWICK TEL

New Brunswick Tel has three fiber optic systems in operation. All of them use cables with 12 multimode fibers transmitting in the 800-900 nm region,

Two of the systems are digital, using semiconductor lasers as sources, and transmitting at 44.73 Mb/s. The first system was installed at the end of 1979 in Shediac. It is an entrance link, running in tandem with a digital microwave radio link. It has a route length of 1.8 km. The second system was installed near the end of 1982 in Fredericton. It is another entrance link with a route length of 2.9 km.

The third system is an analog system, using LED as the light source, and has a route length of 0.5 km. It provides video and audio services to a convention center in St. John's.

A fourth system is now being installed. It is a digital system transmitting at 90 Mb/s at 1300 nm, with semiconductor lasers as the source. The 6-fiber cable is presently undergoing acceptance tests. Technically, it is very similar to the two existing digital links. However, this is a trunk line between St. John's and Rothesay. It is expected to cutover at the end of 1984.

NB Tel has installed all their systems themselves. The two digital systems were bought from Northern Telcom, while the analog video system was from Artel, Massachusettes. The one that is being installed came from Digital Communications Corporation. The cable came from Phillips Cable.

NB Tel is currently examining a number of projects, among which is a feasibility study on the use of fiber to connect the Nova Scotia and the Quebec borders. Even though all the existing systems use multimode fibers, it is expected that future installations will be single-mode systems.

5.8 NEWFOUNDLAND

Newfoundland Telephone has one fiber optic system, which connects the company's Television Operating Center to an Anik C Earth Station. The cable is 9.5 km long and has twelve multimode fibers for message and six for video transmission. The video system, transmitting at 840 nm, is already in service. The digital system, planned to transmit at 135 Mb/s, is expected to cut over in 1985. So far, the video system has been working smoothly, exceeding design specifications in most cases.

Newfoundland Telephone has eleven fiber systems that are being considered. Their cable lengths, bit rates, number of fibers in cable, wavelength of transmission, and the dates at which the systems are scheduled to cut over are given in Table 5.6. All systems will have no repeaters. It is anticipated that most future systems will use single-mode fibers. The systems are designed to incorporate wavelength division multiplexing or to utilize higher bit rates when required. Most cables will have aerial supports, while the rest small number will be put in underground ducts.

TABLE 5.6

NEWFOUNDLAND TELEPHONE CO. FIBER OPTICAL SYSTEMS

SYSTEM	CABLE LENGTH (km)	BIT RATE (Mb/s)	NO. OF FIBERS	WAVELENGTH (nm)	PLANNED IN SERVICE
1	9.5	135	12	1300	MESSAGE 1985
2	5.8	135	16	1300	1985
3	12	135	8	1300	1986
4	12	135	8	1300	1987
5	4.5	135	8	1300	1986
6	24	135	6	1300	1986
7	21	45	6	1300	1989
8	20	45	6	1300	1990
9	22	6	6	1300	1989
10	19	6	6	1300	1989
11	15	6	6	1300	1993

6 CANADIAN INDUSTRIAL RESEARCH AND DEVELOPMENT

6.1 CANSTAR

Canstar is one of the major optical communication manufacturers in Canada, second only to Northern Telecom Limited with its subsidiary, Bell Northern Research. It is a wholly owned subsidiary of Noranda Limited, one of Canada's largest resource and manufacturing companies. With marketing headquarters in Toronto, Canstar provides a complete fiber optic systems capability for telecommunications, industrial control, computer and CATV applications. Full customer support is provided in systems design, implementation and training including electronics, optoelectronics, test equipment and cables.

Canstar produces optical cables with both graded-index and step-index fibers. They may have metallic members or may be completely non-metallic. The number of fibers may vary from 1 to 96. For the short wavelengths, the step-index fibers have losses that are typically below 10.0 dB/km. Graded index cables for 1300 nm have nominal losses of 0.7 to 2.0 dB/km. All their standard cables are made to perform at temperatures between -40 and 50 degrees Celcius, with a maximum variation in the losses of ± 0.1 dB/km over the whole temperature range.

Canstar is a major worldwide supplier of fiber optic couplers. In 1983, it opened a new coupler production facility at its head office location in Toronto. With a staff of over 40, this new facility will provide for full integration of production capabilities with product engineering, design and development and computerized coupler testing. Previously, Canstar manufactured all couplers at its Winnipeg cable plant, which will continue research and development in glass technology, cable and couplers.

Canstar has designed and developed 3 and 4 port and multiport star couplers with a wide range of coupling coefficients, using the fused biconical taper technique, which was invented at the Communications Research Centre, Ottawa. Star couplers with up to 200 ports have been made. Both transmission and reflection types are available. The company supplies couplers made with either graded-index or step-index fibers. Customers may also supply their own fibers to be analyzed for possible use in fabricating couplers to their specifications. A typical star coupler has the following specifications:

(1) 2 ports input by 4 ports output

(2) step-index fiber with 100-micron core and 140 micron outside diameter

(3) less than 1.5 dB excess loss

(4) output uniformity to within 1 dB

Besides cables and couplers, Canstar also manufactures optical line terminating equipments. Their CDS1, CDS1C and CDS2 operate at 1.5, 3.1, and 6.3 Mb/s respectively. They are designed for power utility and industrial application or wherever a low-capacity, short-haul optical transmission link is required. Typical applications are inter- and intra-station and microwave entrance links.

Other products of Canstar include electrooptic modems, absolute attenuation measurement systems, cable termination and fiber distribution panels. The CMS-100K is a full-duplex asynchronous, RS-232C compatible electrooptic modem modular system operating at a transmission rate of up to 100 kb/s over several kilometers of fiber cable. It is designed for digital data transmission between widely separated data terminal equipments. Typical applications are computer to remote terminal, host to satellite computer and computer to process control equipment links.

The fiber optic absolute attenuation Measurement System is designed primarily for field use. The transmitter and receiver are housed in separate transit cases. Applications include cable/link loss measurements and splice or connector loss measurements.

The cable termination and fiber distribution panel facilitate interconnection between fiber optic cable and optical line terminating equipments. The single unit provides safe, systematic storage for excess cable fibers, fiber splices, and fiber pigtail cords. It is designed and engineered for use in telephone, power utility, and industrial environments.

Besides producing individual products and building-block systems, Canstar is also involved in complete communications systems. To date, they have installed or committed to install over 2000 kilometers of fibers. Table 6.1 shows the essential information of their supply record.

Together with the Computer Research Group of the University of Toronto, Canstar has developed the Hubnet, a 50 Mb/s local area

TABLE 6.1

CANSTAR SUPPLY RECORD

YEAR	CUSTOMER	DESCRIPTION	LENGTH (KM)		LOCATION/ROUTE	λ/L.G.	EQPM'T.
			CABLE	FIBER			
1978	BCN	Broad Band Cable Network 430 Mb/s (T)	8	64	London, Ontario	850/m.m.	Harris
1978	Canadian Ministry of Transportation	Data of 1.5 Mb	0.8	1.6	Ottawa International Airport	850/m.m.	-
1979	U.S. Army	High Speed Computer Channels at 400 kbps	0.8	4.8	U.S. Army	850/m.m.	-
1979	CEA	6.3 Mb/s FOTS - H.V. Aerial Ground Wire	2	12	H.P. Lab-Boucherville	850/m.m.	Canstar
1979	Alberta Power	Protection & Control System 1:1 6.3 Mb	2	12	Battle River	850/m.m.	Canstar
1979	CP Telecom	Field Trial Vibration-Environment Test	1.5	6	Vaudreuil, Que.	850/m.m.	-
1980	Panarctic	Severe Weather Test	1.0	12	Melville, Island (75th parallel)	850/m.m.	-
1980	Alberta Government Telephone	Telephone 274 Mb.	55	660	Calgary-Cheadle	850/m.m.	Harris
1980	Dow Chemical	Data & Voice Surveillance	2	12	Polysar-Sarnia	850/m.m.	-
1981/3	Manitoba Telephone System	Message Link 1:1 90 Mb.	24	342.4	Winnipeg-Grassmere Radio	850/m.m.	NEC
1981/8	Manitoba Telephone System	Message Link 1:N 90 Mb.	4	64	Winnipeg-Fort Rouge	850/m.m.	NEC
1981/11	Manitoba Telephone System	Message Link 1:1 90 Mb.	69	410	Winnipeg-Beausejour	850/m.m.	NEC
1981/10	Manitoba Telephone System	Message Link 1:1 90 Mb.	9.5	57	Sherbrook-Winnipeg	850/m.m.	NEC
1982/2	Manitoba Telephone System	Message Link 1:1 90 Mb.	20	120	Stonewall-Winnipeg	850/m.m.	NEC

TABLE 6.1 (continued)

YEAR	CUSTOMER	DESCRIPTION	LENGTH (KM) CABLE	FIBER	LOCATION/ROUTE	λ/L.G.	EQPM'T.
1982/9	Manitoba Telephone System	Message Link 1:1 90 Mb.	7.2	86.4	Galasay-Kildonan	850/m.m.	NEC
1982/9	Manitoba Telephone System	Message Link 1:1 90 Mb.	3.4	34	Empress-Winnipeg	850/m.m.	NEC
1983/2	Manitoba Telephone System	Message 28 T1/T3	-	-	Hazelridge	MUX	NEC
1983/5	Manitoba Telephone System	Message 28 T1/T3	-	-	Fort Rouge	MUX	NEC
1983/5	Manitoba Telephone System	Message Link 1:1 90 Mb.	5.5	82.4	Brandon CU-Brandon Radio	850/m.m.	NEC
1983/5	Manitoba Telephone System	Message Link 1:1 90 Mb.	6	12	Verden-Verden Radio	850/m.m.	NEC
1983/6	Manitoba Telephone System	Message Link 1:1 90 Mb.	-	-	Grassmere Radio-Fort Rouge	-	NEC
1983/7	Manitoba Telephone System	Message Link 1:1 90 Mb.	4.1	32.8	Gateway-Trancona	850/m.m.	NEC
1983/7	Manitoba Telephone System	Message Link 1:1 90 Mb.	2.6	52	Sherbrook-Winnipeg	850/m.m.	NEC
1983	Alberta Power	Interstation Com. 1:1 6.3Mb	4	16	Hanna Alt.	850/m.m.	Canstar
1983	Reed Paper	Video/Data Transmission for Industrial Control	1.5	15	Quebec	850/m.m.	Canstar F.I.
1983	Ontario Hydro	Protection & Control System 1:1 1.5 Mb	5.2	20.8	Toronto-Fairchild	850/m.m.	Canstar Lynch
1983	Ministry of Government	Video Transmission for Teleconferencing and Press Interviews	0.5	2	Queens Park-McDonald Block	850/m.m.	F.I. Canstar

TABLE 6.1 (continued)

YEAR	CUSTOMER	DESCRIPTION	LENGTH (KM)		LOCATION/ROUTE	λ/L.G.	EQPM'T.
			CABLE	FIBER			
1984	Sask Tel	Video Transmission for Broadcasting (equipment only)	-	-	Regina South-Regina 12th Avenue	1300/m.m.	NEC
1984	Manitoba Telephone System	Message 1:1 6.3 Mb	26	208	Pine Falls-Great Falls	850/m.m.	NEC
1984	University of Toronto	Data Network 10 Mb	1.5	18	Sidney Smith Hall -McLennan Phys.Lab -Engineering Annex	850/m.m	Canstar Codenoll

network. It is a multiple access, contention based network, the topology of which is based on a collection of HUBs which interconnect to form a rooted-tree structure.

Hubnet is made up of two building block components, HUBs and Network Access Controllers (NACs). The HUB is the key network element on which HUBNET is based. Every network has one central HUB and may have any number of sub-HUBs. Network Access Controllers provide user access to the network and connect to HUBs via twin fiber optic cable. Network expansion is achieved by cascading HUBs together resulting in a rooted-tree structure which can be configured to satisfy any topological requirement.

A HUB consists of two distinct functions; selection and broadcast. A HUB may be configured to operate as either a central or sub type. A simple program start selects the operating mode. In a central HUB, the output of the selection side is passed directly to the input of the broadcast side. This interconnection is done at electrical levels. In a sub-HUB, the selection side output is not connected directly to its own broadcast side input, but rather is connected by an optical link to an input port of a more "central" parent HUB. The correspondingly numbered output port of the parent HUB is connected back to the broadcast side input of the sub-HUB.

By cascading HUBs in this manner, a rooted-tree topology develops. Sub-HUBs are cascaded together either to suit the particular network geography and/or achieve the necessary number of available NAC attachments. Since all traffic must ultimately flow through the central HUB, it is designed for maximum reliability.

Table 6.2 shows the major characteristics of HUBNET.

TABLE 6.2

MAJOR CHARACTERISTICS OF HUBNET

Data Rate	50 Mb/s packet transmission
Physical Medium	Glass fiber either 50 or 100 micron core with minimum bandwidth of 50 MHz.km
Maximum Link Distance	2 km
Maximum Network Size	Open
Topology	Rooted-tree
Maximum Number of Stations	65,536
Message Protocol	Variable frame size, full acknowledgement delivery
Link Control	Multiple access with collision avoidance, echo detect and re-try

what about its premises and staff?

6.2 FOUNDATION ELECTRONIC INSTRUMENTS INC.

The company was founded in November 1977. Since then, it has been in the forefront of fiber optic communications technology, and has experienced sustained high annual growth.

The company employs 35 scientists, engineers and support staff, ten with university degrees. Total sales for 1980 was over $1 million, increasing to over three times that amount in 1983.

In addition to selling products, the company also provides consulting, custom systems design, field installation services, and tutorial courses in the use and maintenance of its products.

Its principal fiber optic products are: fiber optic data systems, fiber optic video-audio transmission systems, fusion splicers for glass fibers, and optical power meters.

Its FI-7300 analog link has two modules --- a transmitter and a receiver. It is intended for large distances. The FI-7310 voice analog link has two modules --- a modulator and a demodulator. The link is primarily intended for the transmission of a baseband video signal along with its associated audio over a single fiber. The FI-7400 digital fiber optic data link was designed for digital data transmission over single fiber channels. The FI-7500 TR fiber modem is designed for full duplex asynchronous data transmission at rates of 0 to 56 Kb/s. It communicates in full duplex over a single fiber.

The major systems constructed by the company that are in operation includes the following:

35 subscriber broadband fiber optic systems (Yorkville)

7 channel video systems (Ottawa Hydro)

13 channel video systems (Transport Canada)

24 channel video systems

8 channel video systems (Televisa of Mexico)

4 km fiber optic data systems (Ontario)

6 channel video /data fiber optic systems

18 km fiber optic telephone system (Department of Defense)

80 fiber optic systems for satellite ground stations (Ford Aerospace and Harris Corporation)

Bi-directional fiber optic data systems (Bell Canada)

Controlled vapour deposition systems for the manufacture of optical glass fibers

6.3 NORTHERN TELECOM LTD.

Northern Telecom Limited is the second largest designer and manufacturer of telecommunications equipment in North America. It operates 30 manufacturing plants in Canada, two in Malaysia, and one each in the Republic of Ireland, Brazil and England. Research and development is conducted by 27 R & D centers located at these facilities and by Bell-Northern Research Ltd., a subsidiary, which operates 6 research facilities in Canada and 4 in the United States. It is the largest research and development organization in Canada.

Northern Telecom Limited (NT) maintains 17 corporate offices: 5 in Canada, 3 each in the United States and England, 2 in the Republic of Ireland, and one each in France, Switzerland, Singapore, and West Malaysia.

In 1982, revenues were $3.036 billion, up 18.1 percent from $2.571 billion in 1981. Net earnings, before extraordinary gains were $151.2 million, up 25.2 percent from $120.7 million in 1981.

Revenues for subscriber apparatus and business communications and netwrok systems rose by 29.6 percent in 1982. Transmission equipment rose by 30.6 percent. Sales were particularly strong for products such as digital channel banks, the DMS-1 (digital multiplex system), analog and digital microwave radio, and fiber optic systems.

In Canada, Northern Telecom employed 18,964 people in 1982, down 1812 from 20,776 in 1981. Its revenue from Canadian customers were $1.248 billion, or 41.1 percent of the total revenue, compared with $1.248 billion, or 48.5 percent of the total in 1981. Because of the weak Canadian economy in 1982, telephone companies reduced their capital spending plans. NT's revenues from Bell Canada were $845.9 million, or 27.9 percent of the total, compared with $834.5 million, or 32.5 percent of the total in 1981. However, its exports of parts, components, systems, and services out-balanced this relative decline. Export revenues rose by 40.2 percent to $473.9 million from $337.9 million in 1981.

NT's operations in the United States was very successful in 1982. The American Telephone and Telegraph Bell System and its operating companies were the largest single customer of Northern Telecom Inc. (NTI), the operating company of NT in the United States, accounting for US $161 million, up 49 percent from US $108 million in 1981. The most significant single increase was in the digital multiplex systems (DMS). In all, more than 600 DMS-10s were in service at the end of 1982 in the U.S., Canada, and several other countries. NT expected to put more than 300 DMS-10s into service in 1983. In October 1982, it signed a four-year contract with New York Telephone to supply DMS-100s which were expected to be worth more than $150 million US.

NT's international revenues increased 19.09 percent to $325.2 million in 1982 from $271.2 million in 1981. This reflected the gains of all the countries in which Northern Telecom International Limited had established operations.

NT obtained its first international fiber optics order when Barbados Telephone Company contracted for a 14.3 mile optical systems network worth more than $1.5 million.

NT's 1982 expenditures for plant and equipment were $252.6 million, up 20.5 percent from $209.6 million in 1981. It expected its 1983 capital spending to be up by about 23 percent. A significant portion of these investments was for new equipment and business sytems to support productivity and cost-reduction efforts.

Construction is underway for a 377,000 square-foot R & D facility near Ottawa for BNR. This new capital investment will total $37.4 million, the largest single private-sector high-technology project ever undertaken in the Ottawa region. The new BNR laboratory will bring the total NT and BNR investment in the Ottawa region to $174 million.

In March 1982, Northern Telecom Canada Limited officially opened its Saskatoon facility to produce optoelectronics communication systems. The $14 million, 91,000 square-foot facility enables NT to extend its fiber optics marketing activities into international markets. By the end of 1982, NT had sold or had on order 155 fiber optics networks.

N.T. Optical systems revenues in 1982 nearly doubled to more than $37 million. In January 1983, NT announced its first contract for single-mode optical fibers. Single-mode fiber offers three to five more communications channels per fiber than hitherto possible. At a value of over $100 million, the four year contract for delivery of 62,000 miles of fiber optic cable to MCI Communications Corp. is NT's first major optical systems contract in the United States.

OPEN (Open Protocol Enhanced Networks) World is NT's approach to information management systems. OPEN World products, systems, and services will enable organizations to connect many types and makes of equipment in one integrated system that can evolve as requirements and technology evolves. The corporation's five year research and development program through 1987 will include $1.2 billion dedicated to the further development of OPEN World products, services, and features. During the same period, the corporation expects to derive revenues of about $13 billion from Open World products, features and services.

The headquarters and main manufacturing facilities of the Optical Systems Division of NT is Saskatoon, Saskatchewan. Other facilities are located in Ottawa, Kanata, and Atlanta. Fiber preforms are made by the chemical vapour deposition method. The single-mode fibers drawn have core diameters of 8.5 microns while multimode fibers have 50 micron cores. Both of them have quartz claddings.

To cable the fibers, NT has a "reverse-helix" design. An extruded polyethylene plastic case has six or eight oscillating slots. Each slot can hold up to 12 fibers free from tension. A cable may have 96 fibers, but an average number is 24. Smaller cores for 6 to 2 fibers are also produced. The fibers are colour-coded in the PIC standard. Up to three copper pairs may be included for alarm or talk communication. The cables are rugged and may be installed aerially, ducted, or directly buried. They have been field-proven from -40 to 50 degrees Celsius. Ice crushing is eliminated by DRIGEL fill or air pressurization. NT can produce over 5000 km of cables annually.

In addition to fibers and cables, NT is capable of supplying a complete range of telecommunication products, from light sources such as lasers and LEDs, to detectors and systems. Examples of systems are:

(a) FD-2 transmission system (see Fig. 6.1):

- (1) operates at the DS-2 rate of 6.3 Mb/s
- (2) carries up to 96 simultaneous conversations per fiber pair
- (3) may have 30 km repeater spacings at 1300 nm wavelength
- (4) suitable for:
  - (i) medium traffic inter-office trunking
  - (ii) relief for congested copper PCM systems
  - (iii) long thin routes
  - (iv) umbilicals to remote areas

(b) FD-3 transmission (see Figs. 6.2, 6.3):

- (1) operates at 45 Mb/s
- (2) carries up to 12 channels, each channel with up to 672 voice circuits
- (3) may have 25 km repeater spacings at 1300 nm wavelength
- (4) suitable for:
  - (i) medium-haul toll-grade transmission systems
  - (ii) digital entrance links at DS-3 rate

FIGURE 6.1

SYSTEM CONFIGURATION OF FD-2 TRANSMISSION SYSTEM

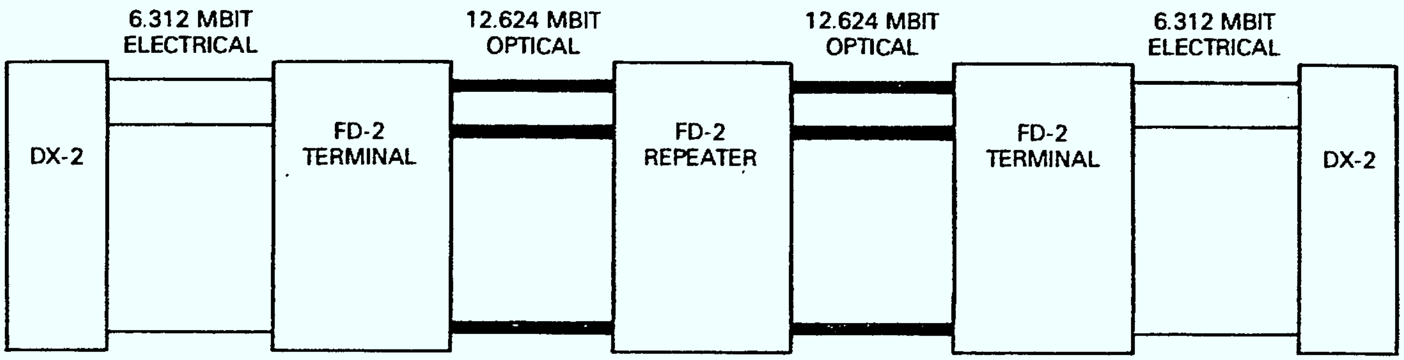


FIGURE 6.2

BLOCK DIAGRAM OF FD-3 TRANSMISSION SYSTEM

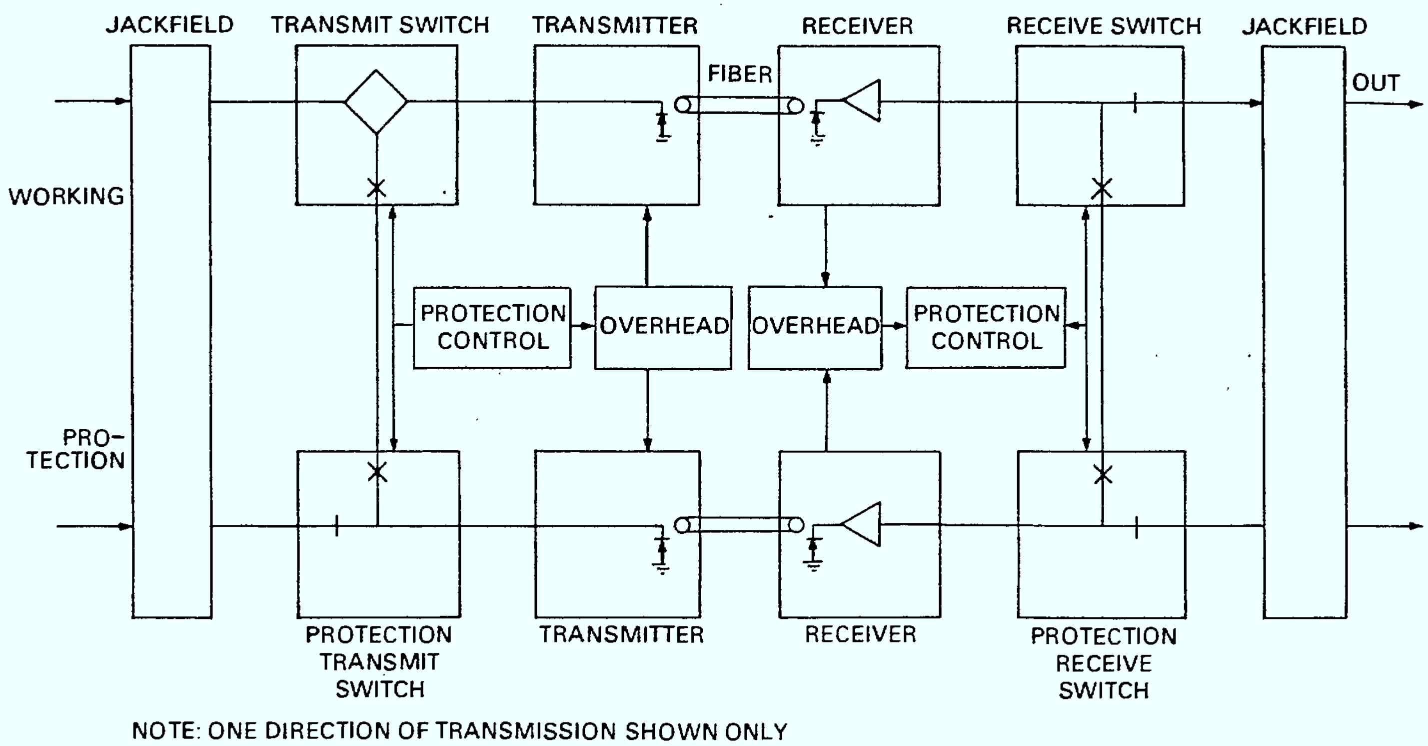
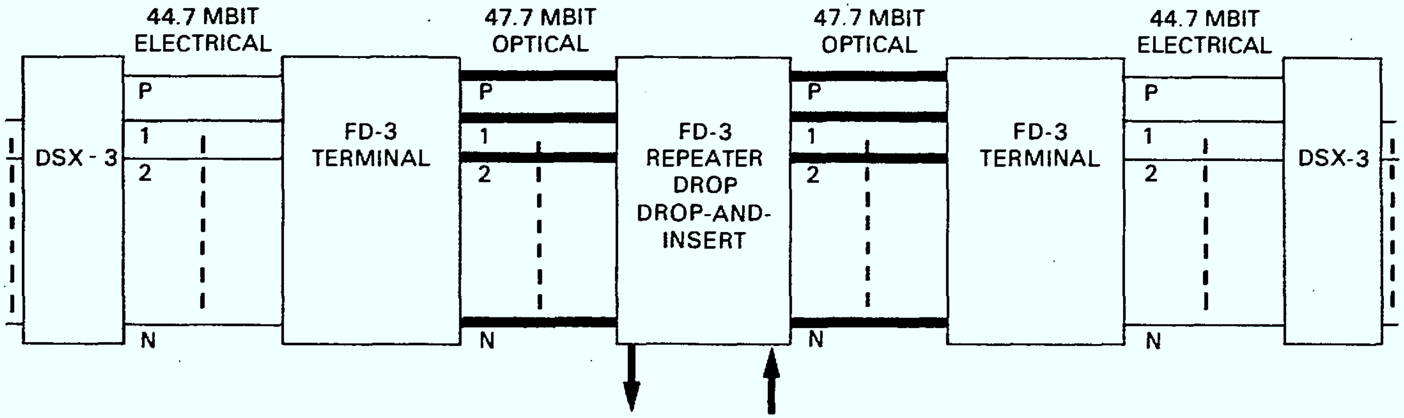


FIGURE 6.3

SYSTEM CONFIGURATION OF FD-3 TRANSMISSION SYSTEM



(iii) digitized video transmission

(iv) inter-office trunk transmission systems

(c) FD-135 transmission system (see Figs. 6.4, 6.5):

(1) has 3x45 Mb/s transmission capacity

(2) has 90 Mb/s option for increased reach

(3) may have 25 km repeater spacings if multimode fibers are used

(4) may have 50 km repeater spacings if single-mode fibers are used

(5) suitable for:

(i) digital entrance links at DS-3 rate

(ii) medium- or long-haul toll grade transmission systems

(iii) digitized video transmission

(iv) inter-office trunking

In addition to the above products, NT also produces wavelength division multiplexers, optical attenuators and other associated tools and test equipments.

FIGURE 6.4

BLOCK DIAGRAM OF FD-135 TRANSMISSION SYSTEM

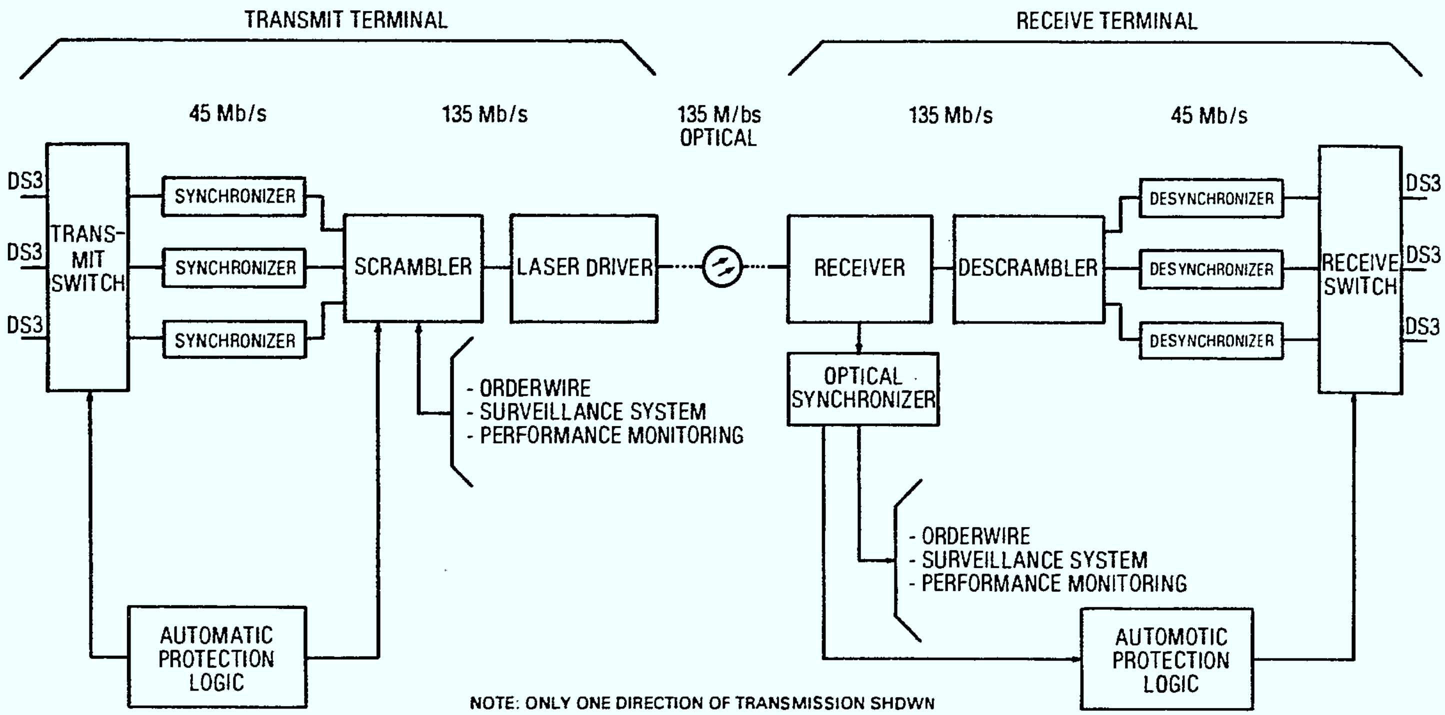
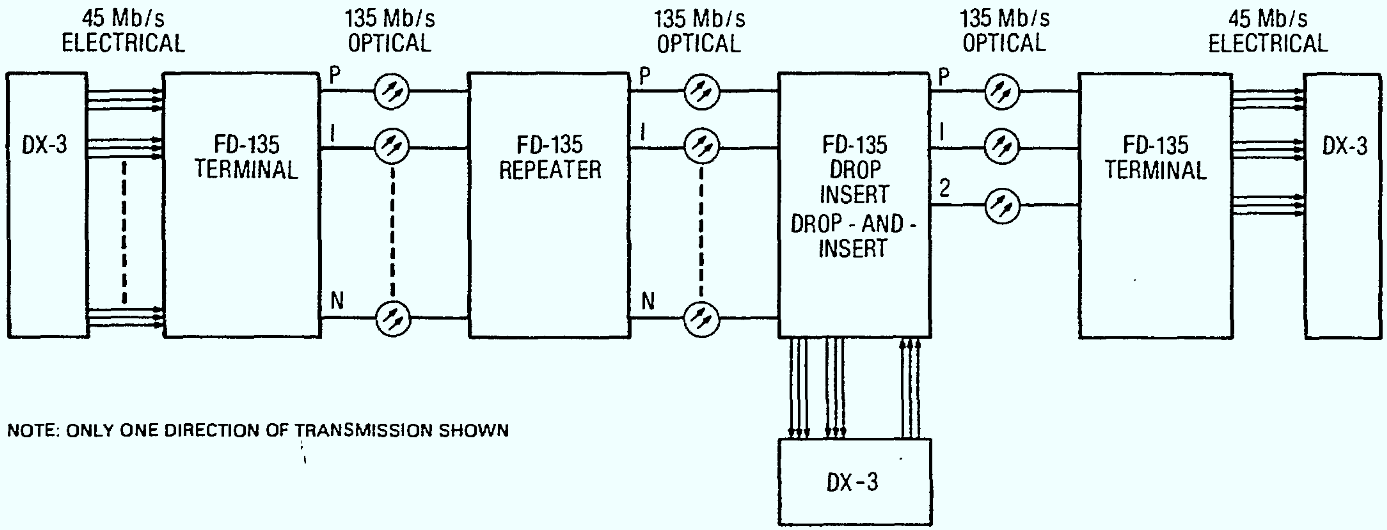


FIGURE 6.5

SYSTEM CONFIGURATION OF FD-135 TRANSMISSION SYSTEM



NOTE: ONLY ONE DIRECTION OF TRANSMISSION SHOWN

6.4 PHILLIPS CABLES

Phillips is one of the major fiber optic communication companies in Canada. It offers complete system and field support, including systems design, on site installation supervision and testing, as well as training courses covering equipment maintenance, cable splicing and testing.

In the 1970's, Phillips Cables began development of its first optical cables. In 1978, 7.4 km of optical cable was supplied to British Columbia Telephone Company and formed the backbone of the first trial, DS-3 (45 Mb/s) fiber optic system to be installed in Canada. This was followed in 1980 with the supply of a complete system to Edmonton Telephones for the first commercial DS-3 fiber optic system in Canada. The system was a 16 km, 12-fiber cable system that linked the Londonderry, Main and Westmount central offices.

The variety of optical cables produced by Phillips includes those with either metallic or dielectric strength members, moisture protection, and special sheaths such as those incoporating rodent proof steel tape, or flame retardant PYC. They also made specialty cables such as FIBRAL composite overhead power or ground conductor which employs an optical core for a communication link.

All Phillips optical cables employ the loose buffer tube design where the optical fibers remain in a relaxed state inside a protective buffer tube.

Table 6.3 is a supply record of Phillips Cables.

TABLE 6.3

PHILLIPS CABLES SUPPLY RECORD

Date	Contractor	Cable Route	Cable Length (km)	Bit Rate	No. of Fibers	Remarks
June, 1980	B.C. Hydro				4,6	Filled, all-dielectric
1980	City of Edmonton	Lendrum Wire Center - Terwillegar Route Location	7	DS-3	12	
1980	City of Edmonton	Edmonton Inter-Office:				
		Main-Westmount	5.9	DS-3	24	
		Main-Bonnie Doon	6.0	DS-3	24	
		Main-Strathcona	3.5	DS-3	24	
		Strathcona-Lendrum	4.2	DS-3	12	
May, 1981	City of Edmonton	Bonnie Doon - Millwoods Wire Centers	9	DS-3	12	
Sept. 1981	Alberta Government Telephones	Edmonton-Nisku-Leduc-Kavanagh	54	DS-3C (90 mb/s)	36, 42, 50	840 nm wavelength
Jan. 1982	Alberta Government Telephones	Grande Prairie Central Office - Grande Prairie Radio Relay Site	3.1	DS-3C	16	Digital Optic link 840 nm wavelength Cable & Equipment
March, 1982	City of Edmonton	Main-Jasper Place - Westmount Wire Centers	13.5		24	

TABLE 6.3 (continued)

Date	Contractor	Cable Route	Cable Length (km)	Bit Rate	No. of Fibers	Remarks
March,1982	British Columbia Telephone Company	Invermere - Invermere Radio Site	9	DS-3 (45 mb/s)	12	
April,1982	Municipality of Anchorage		8.5	90 mb/s	24	850 nm, 1300 nm wavelengths
	Municipality of Anchorage		11.6		24	1300 nm wavelengths
Feb. 1983	City of Edmonton	Westmount-Lendrum-Bonnie Doon-Strathcona Wire Centers		DS-3		Equipment Only
March,1983	New Brunswick Telephone Company	Saint John-Rothesay	17.0		6	

6.5 OTHER RESEARCH AND MANUFACTURING COMPANIES

ASW Controls & Instruments Ltd. specializes in high technology industrial process control/analytical instrumentation for primary industries. Its main interest in fiber optics is presently in the area of industrial sensors and related systems.

Barringer Research Limited has limited use of fiber. At present, fiber is used to link the detector to the measuring system of an air-borne laser fluro sensor.

Canadian Instrumentation and Research Limited is largely a research company. It has a scientific staff of five with degrees, and an extra support staff of six. Its present research effort is directed to accelerometer and rotation sensor. It also has a hydrophone for demonstration purposes. Besides research, it has a standard line of products which are:

Couplers
Interferometric systems
Laser diode power supplies
Integration cavity radiometer
Input optics

Focal Marine Limited is an opto-electronic company formed in April, 1983, as a joint venture of Seimac Limited of Bedford, Nova Scotia, and Dalhousie University. The objectives of the company are:

(1) To provide technical and engineering services to the marine and offshore industries in the application and design of fiber optic based systems and products.

(2) To provide a service and support capability to users of fiber optic devices.

(3) To provide a research and development capability in the use of fiber optic techology at sea.

Focal Marine Limited is currently engaged in contract engineering services for government and industry, studies on fiber optic installation procedures in surface vessels, and trials on fiber optic tow vessels. It has a technical staff of seven persons with degrees and one without. They are supplemeted by two persons in charge of managerial and sales matters. At present, they are working on a fiber optic slip ring. They expect to develop systems for particular shipping requirements in the near future.

JDS Optics Inc. designs, manufactures and sells fiber optic compnents. Its line of products includes:

Couplers (bidirectional, access, star and selfoc couplers)

Optical switches

Fixed and variable optical attenuators

Wavelength division multi/demultiplexers

Its export and domestic sales assume approximately equal proportions. Other than a support staff, it has a scientific personnel of 3 persons with degrees.

Ph. D. Associates Inc. works in close collaboration with York University to make fiber optic computer interface. The company is mainly supported through contract work. However, it also sells some computer software packages. Basically, it has a scientific personnel of 12 persons.

RCA Inc. is an important designer, manufacturer, and vendor of detectors. Its research staff has about 10 persons devoting, on the average, approximately 20% of their time on fiber-related research. The production work force has about 100 persons, and around 25% of them are involved in fiber-related work.

7 GOVERNMENT LABORATORIES

Fiber optic activities in government labs are very limited. If any, the number of researchers working in fibers is usually only one or two who might be only slightly related to fiber. Naturally, the Department of Communications has many activities in this area. Because this Report is written for the Communications Research Centre, a description of the Centre will not be presented. Besides the Centre, there is very significant work in fiber optics carried out by the Fiber Optics and Broadband System R&D of the Department of Communications. Consequently, this section will begin with a brief account of that group.

Broadband System R&D, Department of Communications

The Fiber Optics and Broadband System R&D of the Department of Communications concerns itself mainly with local area network (principally for office automation) and optoelectronic devices such as wavelength division multiplexers.

This group has been very active in advocating broadband fiber optic transmission, and has given a number of important talks to various groups both inside and outside Canada. Technical papers have also been published. It helps companies to develop systems. In general, it helps to promote Canadian companies in this technology, and has already achieved excellent results. It is available for consultation, and welcomes other organizations, especially companies, to discuss relevant matters with it.

Institut National de Recherches Scientifiques

Number of researchers: 4 staff

2 graduate students

Research: Coherent fiber bundle for imaging

Fiber for illumination transmission

National Research Council --- Electrical Engineering

Number of researchers: 1

Research: Fiber optic sensors

National Research Council --- Institute of Material Engineering

Number of researchers: 4

Research: Welding surface inspection system

Fiber optic detection of failure in composite material

National Research Council --- Laser and Plasma Physics

Number of researchers: 2

Research: Use fiber (a) to broaden the spectrum of a picosecond pulse

(b) to compress a pulse down to 30 nsec.

Propagation of pulses in fibers covered with dyes

Waveguides

National Research Council --- Optics

Number of researchers: 1

Research: Fiber optic sensors

Ontario Research Foundation

Number of researchers: 1

Research: Use fiber as light guide for photodetectors

8 ACADEMIC INSTITUTIONS

There were 19 positive replies from universities representing 17 different research groups. Ten of the replies came from departments of engineering, four from physics, three from computing science, and two from astronomy. Three other positive replies came from colleges.

The geographical distribution of the replies were as follow:

Ontario: 8

Quebec: 5

Alberta: 3

British Columbia: 2

Saskatchewan: 2

Manitoba: 1

New Brunswick: 1

The work of each group is described in the alphabetical order of its institution; first the universities, followed by the colleges.

1. University of Alberta

Electrical Engineering

Researchers: 4 professors
8 students
2 technicians

Research and Development: Devices and systems

Different types of modulation to determine suitability for fiber transmission

Design of receivers and transmitters

Stabilization of laser frequency

2. University of British Columbia

Electrical Engineering

Researchers: 3 with degrees

Research: Devices and systems

High voltage optical sensor using fiber optic link for hydro systems

3. University of British Columbia

Geophysics and Astronomy

Research: Low light level imaging systems ---

Design, build and use low light imaging detector systems for astronomical research. Fiber optic image conduits as integral part of some components

4. University of Calgary

Electrical Engineering

Researchers: 3 with degrees

Research and Development:

Devices and systems for communication

Thermo-optic switching
capabilities of different
materials

Analysis of transmission
performance of complex fiber
optic network of mixed topology

5. Concordia University

Electrical Engineering

Researchers: 3 with degrees

Research: Fibers and devices

Polarization rotator, mode converter,
modulator

Analysis of wave propagation in anisotropic
cylindrical dielectrics

6. Universite Laval

Informatique

Researchers: 2 with degrees

1 without degree

Research and Development:

Systems for communication

Computer links

Local area network

Broadband network

7. Universite Laval

Physics

Researchers: 2 faculty plus graduate students

Research: Fiber optics

Integrated optics

Bistability

Interferometry

8. University of Manitoba

Electrical Engineering

Researchers: 2 with degrees

Research: Devices

Germanium photodectors for 1300-1550 nm fiber optic systems

9. McMaster University

Engineering Physics (Communication research Lab)

Researchers: 2 faculty

4 research staff

8 graduate students

Research, Development and Fabrication:

Devices and systems

Photo diodes

Laser diodes

Thin film waveguides and filters

Materials for detectors and sources

Detector configurations

10. University of New Brunswick

Electrical Engineering

Researchers: 2 with degrees

Research: Theoretical study of elliptical fibers

11. Queen's University

Electrical Engineering

Researchers: 1 faculty plus graduate students

Research: Devices and systems for communication

Light emitting diodes

Laser diodes

Photodetectors

12. University of Regina

Electronic Information Systems Engineering

Researchers: 4 with degrees

Research and Development:

Local area network for high voltage electrical switching stations

13. University of Saskatchewan

Mechanical Engineering

Researchers: 1 with degree

3 without degrees

Research and Development:

Fibers and systems

Coating of glass fibers with plastics to minimize entrained bubbles in plastic coating

14. University of Toronto

    Electrical Engineering

    Researchers: 3 with degrees

    Research and Development:

    Fibers and devices

    Fault locator

15. University of Toronto

    Computer Systems Research Group

    Research and Development:

    Fiber optic local area network ---HUBNET

16. University of Toronto

    David Dunlop Observatory

    Researchers: 2 with degrees

    Research and Development:

    Astronomical spectrographs with optical fiber input

17. Wilfrid Laurier University

    Department of Physics and Computing

    Researchers: 4 with degrees

    4 graduate students

3 without degrees

Research and Development:

Devices

Multi/demultiplexers

Couplers

Sensors

Thin films

18. Ecole Polytechnique de Montreal

Researchers: 8 with degrees

Research and Development:

Devices and systems

Couplers

Switches

Sensors

19. Cegep de la Pocatière

Research, Development and Production:

Fiber optic experiment teaching kits

20. Cameron College, Victoria

Use fiber optic instruments for teaching

9 VENDORS

Hewlett-Packard (Canada) Ltd.

Line of products:

- Transmitters
- Receivers
- Cables and fibers
- Connectors
- Multiplexers

Laser Fiber Optics Canda Ltd.

Sales force: 2 persons

Line of products:

- Borescopes
- Cameras and lenses
- Meters and micrometers
- Lasers (such as HeNe and carbon dioxide)
- Cables
- Splicers
- Connectors
- Communication systems
- Multiplexers and Demultiplexers
- Filters
- Single-mode fibers

Megatronix Inc.

Sales force: 7 persons

Line of products:

Cossor --- Portable OTDR for 850, 920, 1300 nm fault location

Optikon corporation Ltd.

Sales force: 3 persons

Line of products:

Power meters

Test stations

OTDR

Spectrum analyzers

Micropositioning devices

Fiber cables

Transmitters

Receivers

Repron Scientific Instruments Ltd.

Sales force: 2 persons

Line of products:

Ando Electric Co. Ltd --- Fiber optic communication measuring sets

Beta Instrument Inc. --- Fiber diameter laser gauges, and diameter indicators, controllers

Fiber Optics Research and Technology Co. ---

Endoscopes

Fiber optic lighting systems

Data communications systems

Fibers

Luxton Corp. --- Fluoroptic thermometers (use fibers)

Opto Micron Industry Co. Ltd. --- Fiber cutters, splicers, connectors, and polishing machines

Optel GmbH --- OTDR optical components

Tasso Inc.

Sales force: 2 persons

Line of products:

Fibres Optiques Industries --- Step-index fibers
Graded index fibers

Radiall Connectors --- Connectors for step-index and graded index fibers

Ungermann-Bass Ltd.

Sales force: 2 persons

Line of products:

Local area network (Net/One), and fiber optic components used in the network.

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