Optical Fiber Communication Systems in Japan

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Introduction

A dream of telecommunication engineers has long been a development of practical transmission media for large capacity transmission systems. In accordance with various microwave and millimeter-wave technologies, coaxial, rectangular and circular waveguides were extensively studied for baseband signal through millimeter-wave signal transmission. The research on optical fibers was motivated by this background with a more ambitious program of attempting to use the entire electromagnetic spectrum for communication. The invention of the laser stimulated the development of optical fibers.

Now nobody questions the sound growth of optical fiber technology in the communication field. Although the initial motivation to develop optical fiber was the realization of a large capacity transmission medium,one now recognizes the revolutionary role of the optical fiber in modern society, being an inevitable tool for realizing an "information society".

This article reviews the R&D activities on optical fiber communication systems that have been recently accomplished in Japan. The paper presented by Dr. Shirahata in this session will review the advances in optical fiber and device technologies in Japan. Together with this article, the reader should consult the above paper for a full understanding of recent developments in optical fiber communication.

System Classification

The most important application of optical fiber communication occurs in transmission systems for a public telecommunication network. At present, the number of telephone subscribers in Japan is about 40 million with an annual growth rate of 1.5 million. In addition to the call-by-call telephone services, it is envisioned to introduce such new services as facsimile, data transmission and various broadband services in domestic telecommunication networks. Optical fiber systems are the keystones for realizing such networks. Table 1 shows the optical fiber systems classified according to the present structure of the network.

The small/medium capacity trunk line system[1] is mainly used for intra-city and short-haul inter-city areas. The bit-rate of this system may be limited to less than 100Mb/s. The large capacity system with more than 400Mb/s [2] will be used for the long-haul inter-city trunk lines. This will result in the reduction of transmission cost and will increase the capabilities of handling various services on the same footing, i.e. using digital format.

The application to subscriber loops is considered a most important use for the optical fiber system because the formation of an "information society" or "fibered society", is not possible without considering its introduction to subscriber loops. The information transmission capability of conventional subscriber lines (paired wires) is limited due to narrow frequency bandwidths only to transmit the voice and low-speed data, whereas that of optical fibers is almost unlimited. Subscriber loops using optical fibers can handle various broad-band services that are envisioned in the future. The WDM (Wavelength Division Multiplexing) technique described later is a key for implementing broad-band subscriber loop systems. The WDM should not be thought of as a simple multiplexing/demultiplexing technique but as a fundamentally important concept* when introduced to subscriber loop systems.

* Remember the influence of the FDM (Frequency Division Multiplexing) in microwave long-haul systems to the realization of nation-wide telephone networks and the influence of LSI and VLSI circuits (a straight forward integration of transistors) in our modern society.

The optical undersea cable transmission systems will open a new era for international telecommunication networks.

In Japanese telecommunication networks, an important application of optical undersea systems will be to bring new services to many adjacent islands[3].

Trunk Transmission Systems

Trunk transmission systems are defined as those systems which connect switching stations so as to provide nation-wide telecommunication services. According to the intra-city and inter-city telephone (and the other service) calls, the transmission systems are named as intra-city and inter-city trunk lines, respectively. The small/medium capacity systems are mainly used for intra-city trunking and the large capacity systems for inter-city trunking.

Figure 1 shows the cumulative route-length distribution of telephone offices, toll centers and telephone repeater stations. From the route-length distribution shown in Fig.1, the intra-city and inter-office systems with a repeater spacing from 8km (50% value) to 15km (90% value) can connect most of the telephone offices without installing intermediate man-hole repeaters. Such systems can only be realized by optical fiber systems. On the other hand, the inter-city systems require the intermediate manhole (or hat) repeaters because the distance between telephone repeater stations exceeds 20km.

The system parameters of the small/medium capacity trunk line systems are shown in Table 2. The repeater spacing of these systems is about 10km for the 0.85um waveband and 20km for the 1.3um waveband, enabling the connection of most of the telephone offices without intermediate man-hole repeaters, as understood from the above description. The optimum bit-rate is determined by the number of present and future calls to be transmitted between telephone offices with reference to system cost. Color TV service is increasing in metropolitan areas and thus, an analog system is also included in the small/medium trunk line systems.

In view of system cost, the inter-city or long-haul transmission systems should be designed to be of as large a capacity as possible, because inter-city calls can be multiplexed at switching stations. Table 3 shows the system parameters of large capacity trunk line systems. Although the present system design considers the use of graded-index multimode fibers, the authors believe in the importance of long-wavelength (1.3~1.6μm) single-mode fiber technology for the long-haul system. The rapid progress of single-mode fiber technology is now underway in Japan. The large-capacity long-haul system are designed to transmit 400Mb/s digital signals (equivalent to 5760 telephone channels) per fiber and thus with few tens of fibers, the total information capacity will exceed a hundred thousand telephone channels.

In addition to these trunking systems, optical fiber intra-office systems can also be realized to help the flexible installation of various in-house equipment at telephone and repeater stations. In particular, a problem of congestion of in-house cables has recently drawn the attention of facility engineers : the optical fiber systems will offer the answer to this problem.

The field trial of the small/medium capacity and intra-office systems was ended last year and their commercial test will start from this year at twelve locations in Japan. The field trial of the large-capacity systems started at the end of last year and will continue until March, 1982. Their commercial test is also scheduled.

Subscriber Loop Systems

As mentioned before, the most important application of optical fiber systems is in subscriber loop systems. The role of telecommunications has been to expand the telephone (and only recently data transmission) services into nation-wide and international scales. Such broad-band services as color TV and radio (AM and FM) are only possible via radio waves even at the modern times, although such services in limited scales are possible with coaxial cables. This is due to the fact that the conventional subscriber loops are constructed with pair cables whose transmission characteristics are far from those required for the transmission of broad-band services. By the same token, coaxial cables are expensive and bulky, thus impractical to use in subscriber loops.

Optical fibers are light-weight, low-loss, wide-band free from crosstalk, do not pick up electrical interference, and, are of low cost. Furthermore, recently produced optical fibers have shown the potential of wide waveband (0.7~1.7μm) capability by reducing the OH ions in the fibers[4]. This last characteristics, i.e. wide waveband is comparable to that of radio waves or millimeter-wave circular waveguides, and gives potential benefits when applied to subscriber loop systems. As mentioned above, the WDM technique is the one to fully utilize this wide waveband characteristic. The WDM technique not only increases the overall transmission capacity but the flexibility of subscriber loop systems. We believe that the WDM technique will open the era of the "information society" or "fibered society" in which various narrow-band and wide-band services are provided for on an entirely personal basis.

In this article, we only show two examples of plausible optical subscriber loop systems. However, we do not know, at present, what sort of subscriber loop systems will evolve in future networks. They depend upon services presently not widely seen, traffic trend, and of cource the optical fiber technology. Instead, what must be done now by telecommunication engineers is the full expansion of possibilities underlying the optical fiber technologies. Various field evaluation tests as well as laboratory ones are essential for this purpose.

Figure 2 shows an experimental model of a subscriber loop system[5]. Using the WDM technique, two one-way color TV channels and several two-way narrow-band channels (telephone, data,etc.) are provided to a subscriber. Two optical channels are prepared by the WDM for future expansion of services. At a center station, a video switch is controlled by a request from the subscriber through an interface equipment that also connects the narrow-band signals transmitted to and from the subscriber to the existing telephone and data networks. In this system (and also for other future systems), micro-computers and micro-processors play very important roles for processing and transmitting/receiving signals.

An optical access-loop (OPAL) system as depicted in Fig.3 [6] is another possible candidate for a subscriber loop system. The OPAL system is composed of a center station and many remote stations, which are connected to one another in loop-wise fasion by an optical fiber high-way. The center station distributes signals received from a remote station to another station inside and/or outside. The distribution of signals is executed by the time-division multiple access scheme. The optical fiber high-way must be wide enough (wide bandwidth) to handle the signal traffic of many remote stations. An optical accessor is placed at the point of access to the high-way. The OPAL network is particulary suited for on-premises applications.

The field trial of an optical subscriber loop system is now underway at the Yokosuka area near Tokyo.

Optical Undersea Transmission Systems

Japan is composed of four main islands and surrounded by many small adjacent islands. The necessity for optical undersea transmission systems increases with a growing need for more advanced nation-wide communication services. Figure 4 shows a picture of domestic undersea cable systems. The large capacity system will mainly be used for connecting four main islands, which, in conjunction with on-land systems, composes the inter-city trunk transmission network. Small and medium capacity systems are used for connecting main and adjacent islands. The optical undersea systems undergo extremely severe environmental and reliability problems. Thus, it is logical to develop these systems according to their technical feasibilities. The first system to be developed will be a non-repeatered system where external repeaters are installed in off-shore terminals. This system is practical and economical because, thanks to the low-loss characteristics of optical fibers, the repeater spacing is expected to exceed more than 40km, covering most of adjacent islands. The second is the development of a repeatered system, analog to the conventional coaxial cable systems.

A keystone for realizing optical undersea systems is of cource the development of low-loss optical undersea cables. One of the problems in designing the cable is the strong pulling tension required when laying and repairing. When performing these operations, the cable is suspended in the sea and elongated about 1% by its in-water weight. For the repeatered system, highly reliable repeaters are required. The over-all repeater reliability is less than 100fits for the transoceanic system, thus the reliability of each component must be of the order of a few fits.

The field trial on the non-repeatered system is now underway near Izu Peninsula, using two off-shore terminals and a 10km long shallow-water undersea cable. The field trial on the repeatered system will be scheduled soon [7].

Non-Public Communication Systems

Optical fiber systems are also expected from the non-public communication users. Such users are power electric companies, automobile industries, transportation companies, and universities, to state a few.

Several such users have already constructed their own systems and operated them without noticable problems. For non-public application of optical fibers, Japan is considered to be one of the leading countries in the world. It is believed that the non-public users of optical fiber systems will rapidly increase on a world-wide scale. This tendency has proven the versatility of optical fiber systems, similar to micro-processor-based calculators that have been rapidly prevailed in the private sector.

It is beyond this article's scope to describe the non-public communication systems in detail. Two such systems are presented here. Table 4 shows a summary of optical fiber systems developed by electric power companies in Japan. The transmission of data, voice and supervisory/control signals is the major purpose of these systems, thus the bit-rate being an order of a few Mb/s. The immunity to pick up of electrical interference is an essential property of fibers for use in these systems.

The digital technique realized by LSI and VLSI circuits and optical fiber technology will make these systems more reliable and economical.

Another application of optical fiber systems is to computer networks. Thanks to the amazing development of LSI and VLSI circuits that have recently been accomplished, computers are getting smaller and smaller and, at the same time, faster and faster. Communication with computers is one of the important concepts in modern business (and at home in the future). Optical fiber data links will become an unbeatable candidate for implementing computer communication networks. Typical configurations of optical data links are shown in Fig.5. System designers must consider in detail various factors that affect the configuration of data links.

Concluding Remarks

The optical fiber communication systems presented here are only a few examples among the systems that will evolve in the future. It is certain that various optical fiber systems will bring a new era of telecommunications, being more economical, broad-band, new-service oriented, more reliable, etc. In order to realize such a new era, two important aspects should be considered by telecommunication engineers. One aspect (system aspect) is that, since the domestic telecommunication network must be organized in a sensible manner, we must envision the future service and network images from which the structure and type of optical fiber systems is determined. The other aspect (research aspect) is that we explore the possibilities underlying optical fiber systems from which the service and network images will be envisioned. In such aspect, the service and network images are closely related to each other. It is essential for engineers especially of optical fiber systems to deeply consider interrelationship of service, network and optical fiber technology.

References

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[5]K.Nosu et al., NTC'80, 34.1.1. (1980).
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Table 1. Classification of Optical Fiber Systems in the Telecommunication Network

Systems	Features
Small/Medium Capacity Trunk Line	Network Digitalization Cost Reduction Efficient Utilization of Underground Facilities
Large Capacity Trunk Line	Cost Reduction Network Digitalization
Subscriber Loop	Introduction of Broadband Services
Undersea Cable Transmission	Increase of Transmission Capacity Network Digitalization Introduction of New Services for Adjacent Islands
Intra-Office Line	Remedy for Cable Congestion Extended Linkage of Transmission/Switching Equipment
Data Link	Non-Inductive/Non-Interferential Line Distribution

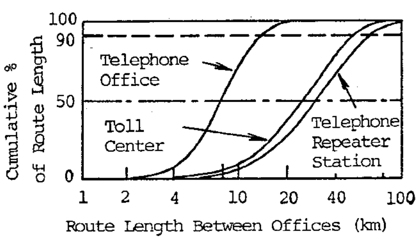


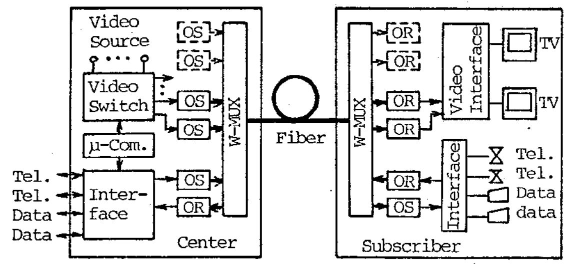
Fig.1. Cumulative Route Length Distribution

Table 2. Field Trial of Small/Medium Capacity Trunk Line Systems

Item \ System		Digital Systems			Analog System
Bit-Rate or Signal		6.3Mb/s	32Mb/s	100Mb/s	CTV Signal
Fiber		Graded-Index Multimode 0.85µm:3.5~4dB/km, 1.3µm:1.2dB/km			
Repeater Spacing	0.85µm	12km	10km	9km	10km
	1.3 µm	—	LD:21km LED:9km	18km	20km
Light Source	0.85µm	GaAlAs-LD			
	1.3 µm	—	InGaAsP LD&LED	InGaAsP-LD	
Detector	0.85µm	Si-APD			
	1.3 µm	Ge-APD			

Table 3. Field Trial of Large Capacity Trunk Line Systems

Item \ System	400Mb/s (GI)	400Mb/s (SM)
Fiber	Graded-Index Multimode (1.2dB/km)	Single Mode (0.7dB/km)
Wavelength	1.3µm	1.3µm
Light Source	InGaAsP-LD	InGaAsP-LD
Detector	Ge-APD	Ge-APD
Repeater Spacing	8km	20km



OS : Optical Sender OR : Optical Receiver
W-MUX : Optical Multiplexer/Demultiplexer

Fig.2. An Experimental System for Video Transmission

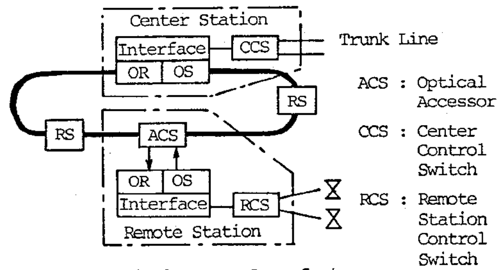
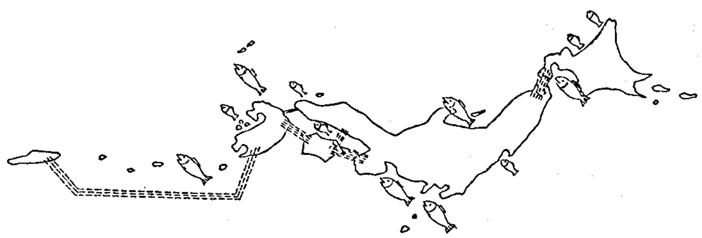


Fig.3. Optical Access-Loop System

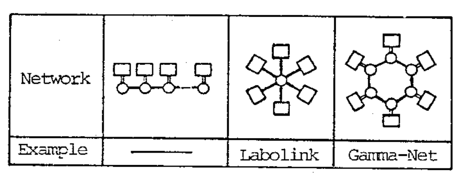


Small Capacity System
Medium Capacity System
Large Capacity System

Fig.4. Application of Undersea Optical Systems to Domestic Telecommunication Network

Table 4. Optical Fiber Systems of Power Companies

Company	Distance (km)	Fiber: Number of Cores	Fiber: Loss (dB/km)	Wave-length (µm)	Bit-Rate (Mb/s)
Tohoku	8	2	—	0.83	6.3
Tokyo	7.5	2	3	0.85	6.3
Tokyo	8	4	—	0.83	32
Chubu	10	4	—	0.83	32
Chugoku	5	2	6	0.83	6.3
Shikoku	6.6	2	3	0.83	6.3
Kyushu	6.3	4	5.6	0.83	32



— Optical Fiber
▭ Host CPU
O Optical Equipment

Fig.5. Typical Optical Network Configuration