FIBER-OPTIC TRANSMISSION SYSTEMS IN JAPAN

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ABSTRACT

This paper describes the main systems that have been developed to date, and some of the technologies for future systems that are now being researched by NTT.

1. INTRODUCTION

Since optical fiber has low-loss and low-dispersion characteristics in the wavelength region of semiconductor laser emission, and since it is small in diameter and light as well, fiber-optic transmission systems have been extensively developed and installed world-wide.

In fiber-optic transmission systems, signals are transmitted in a closed medium (i.e. optical fiber), in contrast to the case of radio transmission systems. Each system is independent and, hence, powers and wavelengths of transmitters can be freely chosen. Moreover, since optical carrier frequencies are high, modulation capacity of fiber-optic system can be, in principle, large in comparison with microwave- and millimeter-wave radio systems.

However, there are several problems for fiber optic transmission systems, they include : (1) High accuracy is required for the fabrication of devices and components ; (2) Functions obtainable with optical devices and components are limited ; (3) Accurate control of phase or frequency is difficult. These problems need be overcom to develop advanced systems.

This paper describes the main systems that have been developed to date, and some of the technologies for future systems that are now being researched by NTT.

2. SYSTEMS FOR COMMERCIAL APPLICATIONS

Medium capacity trunk transmission systems (100 Mb/s and 32 Mb/s) using graded-index multimode fibers were the first systems commercially used in Japan. These were introduced in 1981, and applied in interoffice and medium-haul intercity transmission systems. For short haul intercity applications, a small capacity (6Mb/s) transmission system was also developed. This system employs multimode fibers and WDM (Wavelength-Division-Multiplexing) technology with 1.2μm and 1.3μm wavelengths. This system was introduced in 1983.

The first system employing single-mode fiber was the F-400M system (400 Mb/s) with a 1.3μm wavelength. This system was developed for long-haul intercity trunk transmission lines. The F-400M system was commercially introduced in 1983, and the main trunk line from Asahikawa to Kagoshima was successfully completed. Since Japan comprises four main islands, submarine transmission systems play an important role in telecommunications. In addition to several repeaterless systems using multimode fibers, a

0149-645X/88/0000-0827$01.00 © 1988 IEEE

large capacity system (FS-400M) with repeaters using single-mode fibers was developed. It was introduced between Miyazaki and Naha (800km), and between Hachinohe and Tomakomai (300km) in 1986. Figure 1 shows routes of the F-400M and FS-400M systems.

Large capacity systems can effectively accomodate rapidly increasing demand for information transmission with low cost. The F-1.6G system with a 1.6Gb/s bit rate was developed and introduced in 1987. In high-bit-rate transmission, the bit-rate distance product of the system is limited by the mode partition noise of laser diode (LD). By the use of distributed-feedback LD's (DFB-LD's) in the F-1.6G system in place of Fabry-Perot laser diodes (FP-LD's), the mode partition noise was significantly decreased. Main features of the F-1.6G system are shown together those of F-400M in Table 1.

To apply the low loss properties of optical fibers to long-span transmission systems, the 1.55μm wavelength band is favorable. However, a converntional fiber has a high chromatic dispersion in this wavelength band. Single-longitudinal-mode LD's are indispensable in order to overcome mode partition effects in high bit rate systems. The two systems with 1.55μm wavelength shown in Table 1 are under development. For undersea communication systems in Japan, a repeater spacing of up to 120km makes it possible to construct most undersea systems without costly undersea repeaters.

To accomodate the increasing demand on telecommunication, the channel capacity of subscriber loop lines must be enlarged. Fiber-optic transmission systems are suitable for this purpose. In Japan, a field trial of subscriber loop systems including fiber-optic systems as well as metalic systems was carried out in Tokyo from 1984 to 1987.

The key technologies needed in the application of fiber-optic transmission to subscriber loops are: (1)wavelength division multiplexing technology for multichannel transmission ; (2)modulation and demodulation technology for various signals ; (3)cabling and splicing technology for optical fiber networks ; and (4)cost reduction of optical devices and components.

Figure 2 shows a wavelength division multiplexer module developed for subscriber loop system applications. Light emitters, light detectors, lenses, an optical filter, etc. are laid and fixed on a substrate without any manipulation during the fabrication process.

3. ADVANCED TECHNOLOGIES FOR FUTURE TRANSMISSION SYSTEMS

If we limit our discussion only to the 1.55μm wavelength region where fiber loss is a minimum, available wavelength bandwidth is not less than about 200nm.This bandwidth corresponds to about 27 THz, which is about 6.8×10^6 voice channels. However, conventional fiber-optic transmission systems utilize only a minute part of this inexhaustible capacity. Even the F-1.6G system utilizes about only one eight thousandth of the available bandwidth.

On the other hand, in long-span transmission systems such as submarine transmission systems, repeater spacing is an important factor that determines the total system cost. Figure 3 shows the effect of repeater spacing expansion on system cost reduction. Repeater cost is assumed equal to the cost of a cable R km in length. L is total system span. l_0 and l_1 are original and expanded repeater spacings, respectively.

To expand available wavelength (frequency) band, and to expand repeater spacing, various technical innovations are expected. One method of increasing the available wavelength (frequency) band is high speed modulation. Figure 4 shows an example of high speed LD modulation. By using a gain-switched DFB-LD, an optical pulse width of 25 ps was obtained. The short pulses were modulated by $LiNbO_3$ external modulators and were multiplexed by an optical coupler. By using these technologies, transmission rates as high as 10-50 Gb/s will be feasible by developing an optical demultiplexer technology. Optical nonlinear effect is a candidate for high speed processing of optical signals.

Another method of increasing the available wavelength (frequency) band is optical frequency division multiplexing (FDM). Since current LD's have single longitudinal mode with spectrum width of less than 20 MHz, optical channels can be densely aligned with a frequency spacing in the order of GHz. Thus, total transmission capacity can be increased in proportion to the number of optical channels.

Technology similar to that used by periodic filters and ring cavities developed for micro- and millimeter-wave transmission systems are expected to be useful for such multiplexing. Multichannel LD frequency stabilization is also an important technology. An experiment multiplexing eight optical channels with a 5 GHz spacing has confirmed the feasibility of optical FDM.

By using both of the above-mentioned approaches, we will be able to effectively utilize the inherent wide wavelength (frequency) band of optical fibers. We can expect that we will, ultimately, have a fiber-optic transmission systems with total capacities of the order of Tb/s. Figure 5 shows technology options important for the realization of Tb/s transmission systems.

Since current LD's have narrow spectrum width, heterodyne and homodyne detection tecniques, which are widely used in radio transmissions, can be applied to fiber optic transmissions. These techniques improve detection sensitivity of an optical receiver more than 15 dB, eliminate the effect of mode partition noise, and compensate the chromatic dispersion of optical fiber in an electric stage.

Although external optical modulator is required for ASK and PSK, direct modulation of LD can be adopted for FSK. By using 1.55μm DFB-LD's and InGaAs PIN photo diodes, FSK transmission experiments with 400Mb/s bit rate - 290km span and with 4Gb/s bit rate-155km span, have been successfully carried out. Polarization fluctuation in a fiber is a new problem in heterodyne and homodyne detections, which is absent in the conventional fiber-optic systems. Figure 6 shows results of experiments on high bit rate and long span transmissions reported so far.

4. CONCLUSION

Fiber optic transmission systems developed and under development by NTT are serveyed. To effectively utilize the inherent wide wavelength (frequency) band of optical fibers, transmission systems with a total capacity of Tb/s should be the new research target. Long span transmission technology such as heterodyne detection is also important for future telecommunication networks.

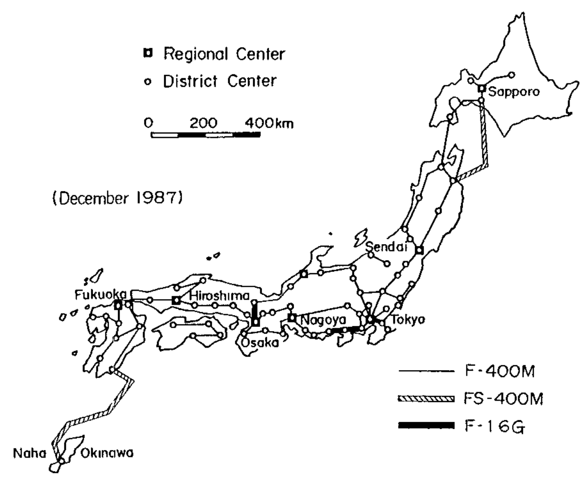

Fig.1 Route map of fiber-optic transmission systems in Japan.

Table 1 Main features of optical trunk transmission systems.

System	F-400M		F-1.6G	
Channel capacity	5760 ch/sys		23040 ch/sys	
Line rate	445.837 Mb/s		1820.90 Mb/s	
Optical source (InGaAs/InP)	FP-LD	DFB-LD		
Wavelength λ (μm)	1.31	1.55	1.31	1.55
Optical detector	Ge-APD	InGaAs-APD		
Zero dispersion λ (μm)	1.31	1.55	1.31	1.55
Repeater spacing (km)	40	80 ~ 120	40	80 ~ 120
Status	Commercial	Field Test	Commercial	Field test

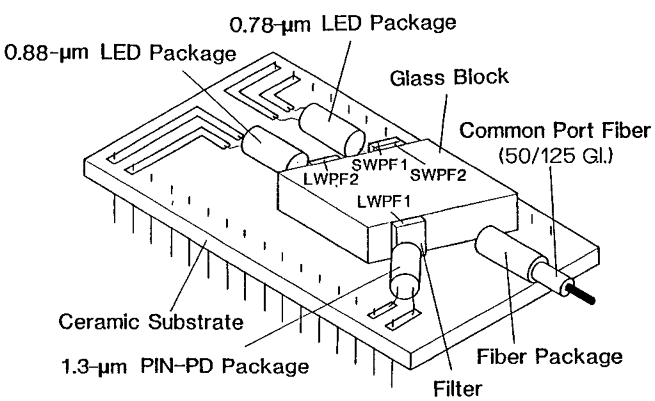

Fig.2 Structure of WDM module.

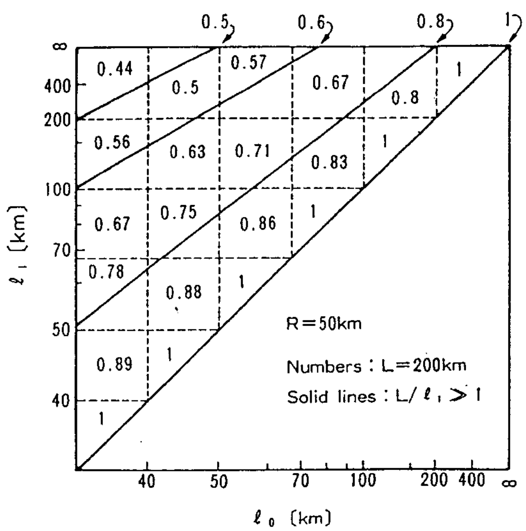

Fig.3 System cost reduction coefficient due to repeater spacing expansion,

l_0 : original repeater spacing,

l_1 : expanded repeater spacing.

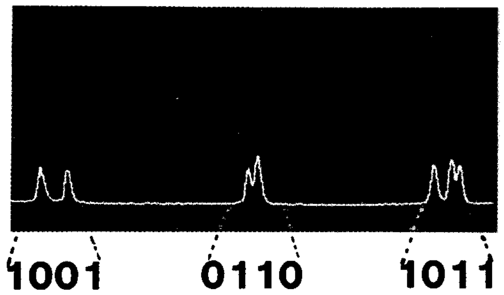

Fig.4 Generation of ultrashort optical pulse train at 50Gb/s by optical TDM.

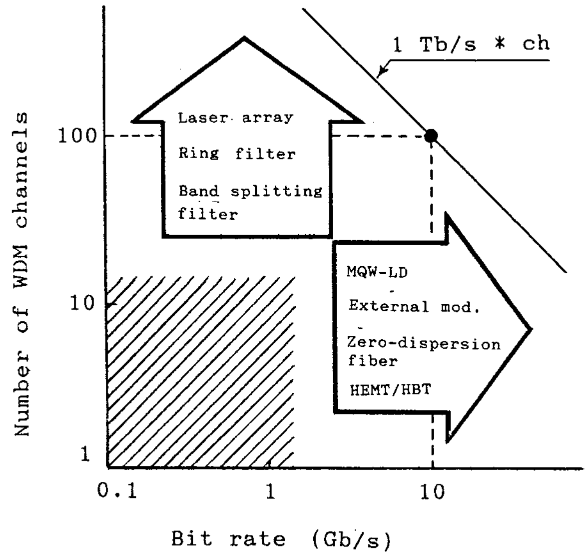

Fig.5 Technology options for the realization of Tb/s transmission.

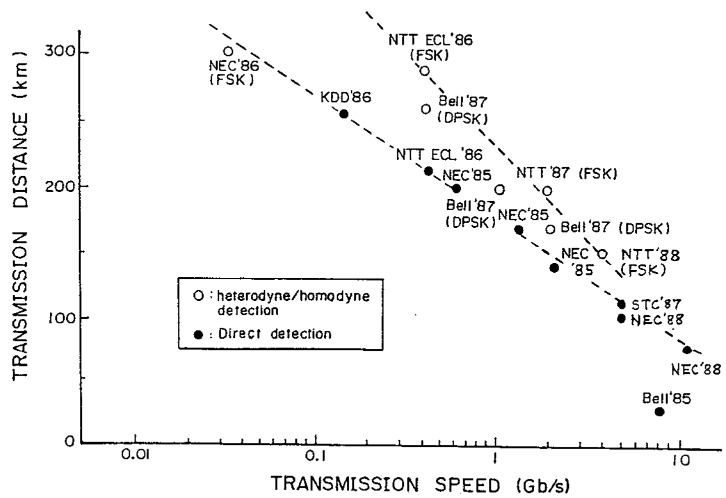

Fig.6 High bit rate and long span transmission experiments.