Ultrahigh Speed Optical Transmission Systems in Japan

Kiyoshi Nakagawa Kohji Hohkawa Kazuo Hagimoto

NTT Transmission Systems Laboratories
Nippon Telegraph and Telephone Corporation
1-2356 Take Yokosuka, Kanagawa 238-03 Japan

Abstract

This paper presents an overview of the current state of ultrahigh speed transmission systems in Japan. Recent progress in optical fiber transmission systems developed in NTT are reviewed. Transmission experiments and key technologies required for constructing ultrahigh speed transmission systems are also discussed.

1. Introduction

With the advent of the information society in Japan, various kinds of broadband services have been provided through telecommunication networks, such as TV conferencing, video information retrieval, high speed digital leased circuits, and CATV. Fiber optic transmission systems have been introduced into existing communication networks to support these information services as well as conventional and advanced telephone services.

Additional growth in the capacity of the future video transmission systems is anticipated. At present, the optical fiber transmission capacity has reached the gigabit-per-second range. However, this is insufficient for the coming broadband ISDN (B-ISDN), which will have to deal with high-speed bulk information such as 150Mb/s high definition TV traffic. An improvement of a magnitude of two or three orders in transmission capacity is required. Emphasis should be placed on ultrahigh speed technology for multi-gigabit-per second optical fiber transmission.

2. Progress on high speed optical transmission systems in Japan

A decade ago, optical fiber transmission depended on multi-mode optical fiber cables and short-wavelength optical devices, and was mainly used for short-distance links. The development of single-mode optical fiber cables and long-wavelength optical devices a highly coherent laser light and high speed Si and GaAs IC's has greatly enhanced the development of optical transmission systems.

The first single-mode fiber system F-400M used a long-wavelength Fabry Perot laser which could generate optical short pulses but restricted repeater spacing due to mode partition noise. Therefore, the wavelength of the system is specified as the minimum dispersion region of the single-mode fiber.

Realizing a larger capacity system or a longer repeater spacing system required the development of a single-longitudinal-mode laser diode (SLM-LD) to overcome residual dispersion of single-mode fibers even near the zero dispersion wavelength region. An excellent SLM-LD, called a distributed feedback LD (DFB-LD), with high speed direct modulation characteristics and high power output was introduced and the first Gbit-per-second system, F-1.6G was developed. The F-400M and F-1.6G systems are now used as the backbone networks for the ISDN services started in April 1988 as well as for conventional analog telephones [1].

A worldwide standard for synchronous digital interface, Network Node Interface (NNI), has been achieved in the CCITT [2]. This is expected to permit efficient construction of digital networks, including broadband ISDN, and effective network operation, administration and maintenance. 600Mb/s and 2.4Gb/s systems have been developed and are now in commercial operation. NTT has also developed a 1.8 Gb/s 100km repeater spacing submarine repeated transmission system, FS-1.8G (with 12 STM-1 channels constructed by multiplexing three STM-4 channels).

3. Ultrahigh speed transmission experiment

Recently, it was shown that a practical Gbit/s system operating at 1.55um wavelength with over 100km repeater spacing required the use of 1.55um zero dispersion fibers in order to be free from impairments caused by chirping and the side-mode oscillation of the DFB-LD. High speed optical transmitters utilizing an LD direct modulation scheme or an external modulation scheme and an ultrahigh speed electric circuits have been studied and multi-Gbit/s optical transmission experiments have been demonstrated [3][4].

During the past few years, optical high speed transmission technologies have progressed significantly through the advent of optical amplifiers. Optical amplifiers have essentially much wider broadband and higher gain than electronic amplifiers. Several kinds of optical amplifiers have been studied extensively. Among then, the Erbium doped fiber amplifier (EDFA) shown in Figure 1 has several advantages. It offers wide bandwidth, high gain with non-sensitivity to input signal polarization, and can operate as an ideal traveling-wave type amplifier since it can be directly spliced to transmission fibers with extremely low reflection. By using EDFA, ultra-high speed optical signal (in the range of 10Gb/s), are directly amplified with low noise, and branching loss can be easily compensated and repeater spacing can be easily increased. This means that an ultra-high speed re-

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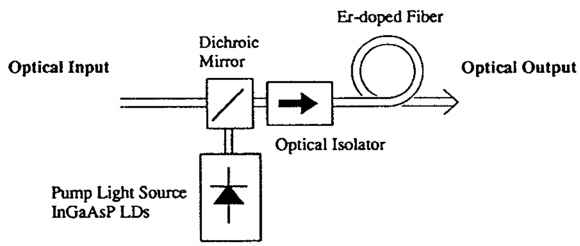
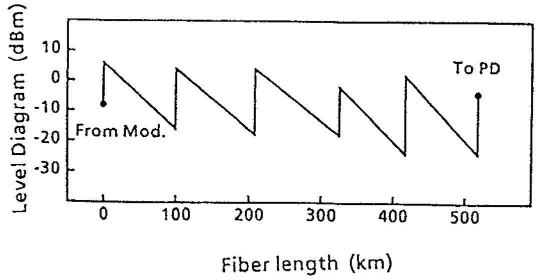
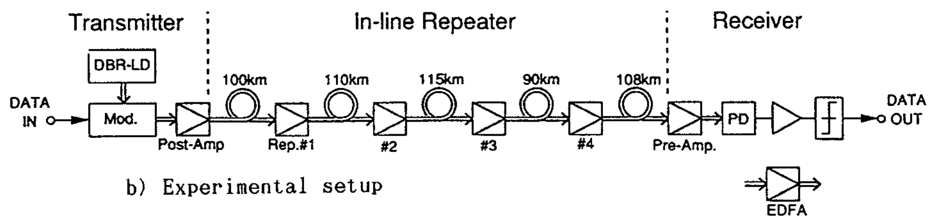


Fig. 1 Configuration of Er-doped fiber amplifier



a) Level diagram



b) Experimental setup

Fig. 2 Bit rate flexible transmission experiment

peater and extremely flexible transmission systems can be constructed with a simple structure. Increasing repeater spacing will reduce transmission equipment cost, improve line reliability, and simplify maintenance and operation functions, because most major telephone offices will be connected without any outside repeaters [5].

Recently, many experiments demonstrating the effectiveness of fiber amplifiers have been carried out successfully in Japan. Non-repeated 250km transmission at 1.8Gb/s [6], 201km at 5Gb/s and 161km at 10Gb/s have been demonstrated. For long haul regenerative application, 2.5Gb/s 2220km links using 25 cascaded EDFA's [7] and 10Gb/s, 505km transmission experiments have been demonstrated [8]. In an advanced ultrahigh speed optical transmission experiment, a bit rate flexible transmission system with 5 Tb/s*km capacity [8], the experimental set up of which is shown in Figure 2, was also demonstrated.

Optical amplifiers are now being applied to construct many excellent systems. Among these, a cross-connect system, subscriber loop system and broadband distribution systems are expected and are now under development.

4. Technology of ultrahigh speed transmission systems

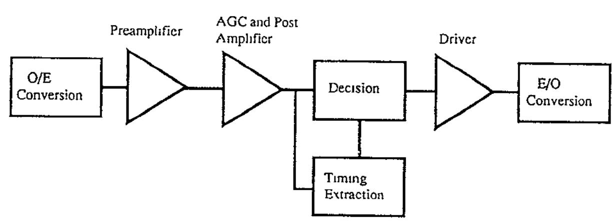
A typical high speed optical transmission system configuration is shown in Figure 3. The advent of the EDFA has made the easy construction of ultrahigh speed optical repeaters possible. In constructing ultrahigh speed digital transmission systems, a high speed transmitter, receiver, multiplexer and demultiplexer are required. To realize such a components, ultra-high speed electrical devices are required in addition to optical devices.

4.1 Integrated circuit technology

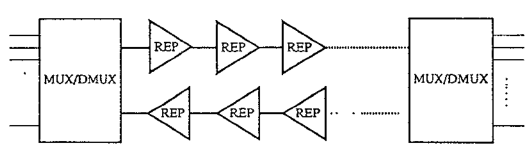
In Figure 4, the trend in integrated circuit technology is shown. Recently, NTT has developed two IC technologies. One, called SST, is a Si bipolar process employing advanced Super Self-aligned process Technology with collector ion implantation. With this technology, a high cutoff frequency of around 25GHz has been achieved [9]. The other is a sub-micron gate length GaAs MESFET process utilizing SAINT (Self Aligned Implantation for N+ layer Technology) with low energy ion implantation , rapid thermal annealing, and submicron photolithography [10]. With this technology, a very high cutoff frequency of 70 GHz has been attained. NTT is also developing an HBT (Hetero Bipolar transistor) [11].

4.2 Multiplexer and Demultiplexer

In a high speed optical transmission system, multiplexer (MUX) and demultiplexer (DMUX) IC's play an important role in bridging the gap between the higher and lower operating speed stages. This is because it is impossible to construct these circuits through the use of a hybrid circuit with discrete elements. The simplest MUX and DMUX are



a) Regenerative repeater



b) System blockdiagram

Fig. 3 Configuration of optical transmission system constructed using small scale integrated circuits (D-type flip/flop IC's and frequency divider IC's). By using Si-bipolar IC's, it is possible to construct circuits which operate at a speed of around 5 Gb/s. Operation speed is expected to reach 10Gb/s in the near future. MESFET IC's have made it possible for medium scale integrated circuits to operate at 10Gb/s as shown in Figure 5. Through the use of a 0.15um MESFET process, a gate family whose operation speed is 10Gb/s for MSI and 13Gb/s for SSI has been realized.

Great progress have been made in the area of HBT IC's and operating speed of more than 10Gb/s has been realized. Such IC's are now in the development stage in several companies in Japan.

4.3 Transmitter and receiver

Most schemes being studied for E/O conversion are either LD direct modulation or external modulation. The former, having a simple structure, are restricted to use in medium span systems, because existing LDs generate optical pulses with chirping when driven with large signal amplitude. The latter have an extremely broad modulation band and negligible chirping. For example, a $Ti:LiNbO_3$ Mach-Zehnder intensity modulator with no chirping produces the best of all modulation characteristics and also has a bandwidth of more than 20GHz. Insertion loss was the major problem, but the use of optical amplifiers as post-amplifiers solved it. Experiments confirm that regenerative repeater spacing is lengthened with little influence from fiber or and dispersions.

O/E conversion can be done with an avalanche photo-diode (APD) and a p-i-n PD. As the transmission signal speed becomes higher, the difference between optical output power and the receiver detectable power becomes increasingly small. To overcome this problem, increasing the GB products of APD has been studied and high performance devices, such as a high-speed InGaAs/InAlAs superlattice APD have been investigated. However, a product value which is large enough to obtain optimum multiplication factor at 10Gb/s has not been obtained. Since the bandwidth of a PIN-PD is superior to that of an APD, PIN-PD and EDFA combination is the best scheme for ultrahigh speed systems. Many ultrahigh speed transmission experiments employing this scheme have been demonstrated [12],[13].

The preamplifier is the dominant device with regard to S/N and repeating speed. Therefore, broadband amplifiers have to be designed taking noise as well as frequency characteristics into consideration. To realize ultrahigh speed receivers, hybrid circuits employing HEMT or GaAs FETs and monolithic IC's have been investigated and technologies to improve frequency characteristics, such as peaking and special packaging have been proposed. In a recent experiment, successful operation of more than 10Gb/s using GaAs MESFETs and HBTs were reported.

The basic function of a decision circuit is the same as that of clocked latch DFF. In order to obtain high sensitivity characteristics, a front amplifier is incorporated into the chip. Figure 7 shows experimental results obtained with MESFET

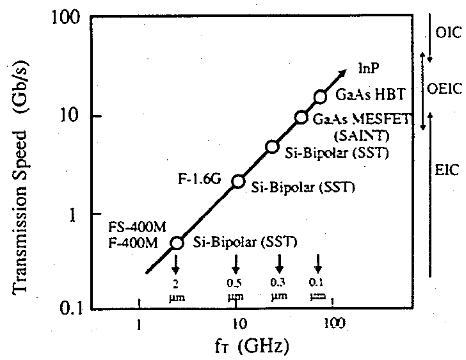
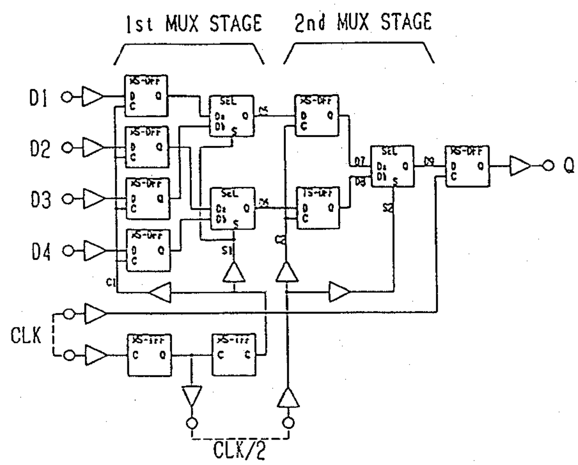
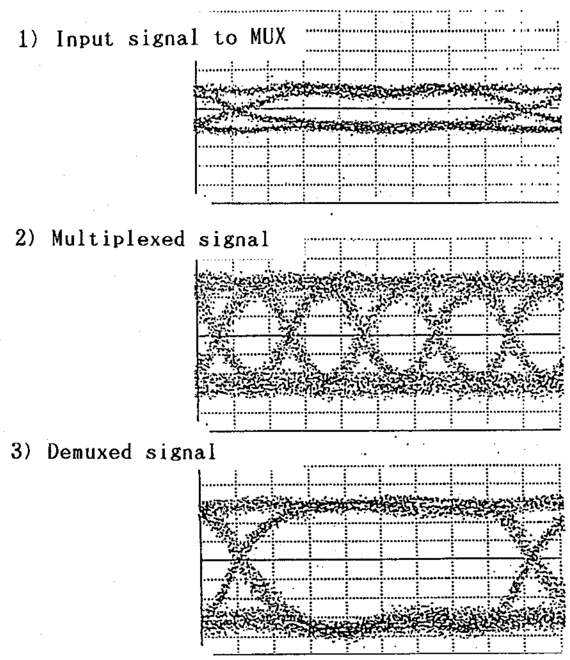


Fig.4 IC trend for multi-Gb/s transmission



a) 4:1 MUX circuit blockdiagram



b) MUX/DMUX Waveform

Fig.5 MESFET-MSI Experiment

and HBT IC's [11],[14].

A narrow-bandwidth high Q filter is necessary to construct a timing extraction circuit. It is difficult to realize a SAW filter at a frequency range higher than 3GHz. As one method to overcome this difficulty, NEC proposed a 1/N countdown timing extraction method [15], which employs a SAW filter tuned to a 1/N data transmission rate. Another method is to use dielectric resonators which have a simple structure and small size in the higher frequency range. With this method, a timing extraction experiment near 10Gb/s has been carried out. In this experiment, an additional wide-band filter was connected in series to eliminate spurious higher modes [16].

In NTT, optical soliton [17] and coherent transmission systems[18] are also under study as future ultra-high speed and long-haul transmission systems. The possibilities for high-speed long-haul system is now being revealed by many transmission experiments. In addition, all optic signal processing techniques, such as the use of nonlinear optic Kerr switches [9], are being studied to realize still higher speeds (in the 100Gb/s range).

5. Conclusion

Optical fiber transmission technologies are rapidly producing higher and better system performances. Ultrahigh speed optical transmission technologies now range over 10 Gb/s, and by employing optical fiber amplifier, flexible high performance transmission systems will be constructed in the near future. These advanced optical technologies will have a significant impact on future communication systems.

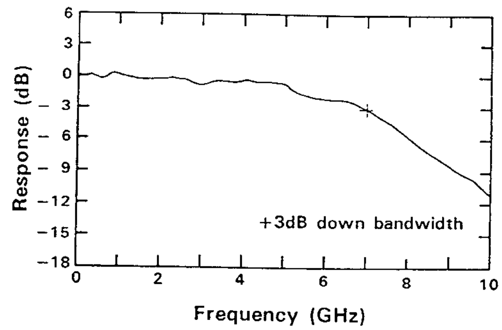


Fig.6 Frequency response of GaAs fornt-end circuit with as PIN-PD

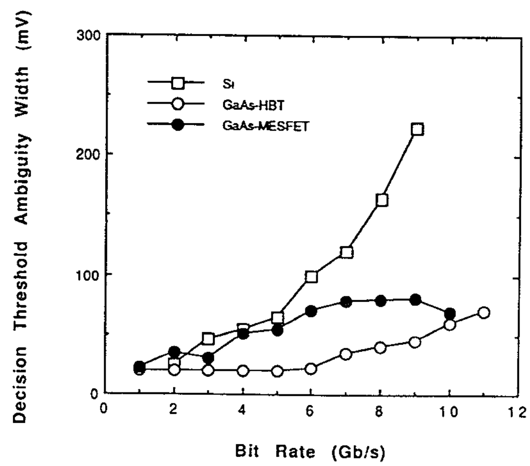


Fig.7 IC sensitivity at multi-Gb/s speed

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