

SONET/SDH Optical Transmission System

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This paper describes Fujitsu's SONET/SDH transmission system.

Fujitsu produces the Fujitsu Lightwave Add/Drop Shuttle (FLASH) series, which conform to the SONET/SDH standard. The FLASH series was well received in the North America market.

Also, this paper describes Fujitsu's plans for future equipment and the key technologies used in some of Fujitsu's new optical transmission systems.

1. Introduction

Ten years ago Fujitsu introduced the Fujitsu Lightwave Multiplexer (FLM) series. The FLM series conform to the SONET hierarchy for North America and the total SONET system approach of the North America transmission market. Fujitsu has supplied the FLM 150 ADM (Add/Drop Multiplexer), FLM 600 ADM, and FLM 2400 ADM. This equipment was well received in the North America market.

For the next generation of SONET/SDH transmission systems, Fujitsu has introduced the Fujitsu Lightwave Add/Drop Shuttle (FLASH). The FLASH series has a ring interconnection within the equipment and a large-capacity cross connect function.

This paper describes Fujitsu's approach to providing a total SONET/SDH transport system. It covers the key technologies of Fujitsu's new optical transmission systems for the Optical Carrier Levels OC-3/STM-1 (155.52 Mb/s), OC-12/STM-4 (622.08 Mb/s), OC-48/STM-16 (2488.32 Mb/s), and OC-192/STM-64 (9953.28 Mb/s) of the SONET/SDH multiplexer hierarchy.

This paper also outlines the following Fujitsu SONET/SDH products that are already in produc-

tion: the FLASH-192 with OC-192 optical line interfaces and the FLASH 600 ADX with OC-12 optical line interfaces.¹⁾⁻⁷⁾

2. FLASH system outline

The Fujitsu SONET/SDH FLASH optical digital multiplexer systems conform to the SONET/SDH hierarchy. These systems operate at the OC-3/STM-1, OC-12/STM-4, OC-48/STM-16, and OC-192/STM-64 rates and can be used in a SONET/SDH network.

2.1 FLASH system application

Fujitsu's SONET/SDH optical transmission equipment has mostly been used in ring networks with Add/Drop Multiplexers (ADMs). The Uni-directional Path Switched Ring (UPSR) application is used for local areas, and the Bi-directional Line Switched Ring (BLSR) is used for long distances. An expanding ring network uses the ring interconnection, which is realized using equipment such as the OC-192 BLSR and OC-48 BLSR inside the FLASH-192.

The ring network provides high quality, network survivability, and self-healing. To cope with the growing number of services required by cus-

tomers, the operating companies require a network which can be remotely and flexibly configured according to the customer's needs.

An interoperability capability was developed to allow multi-vender networks to be created which include the signal transport and Operation Administration, Maintenance and Provisioning (OAM&P) functions required by the operating companies.

The FLASH systems also provide the Software DownLoad (SWDL) function. The SWDL protocol can be overridden for interoperability. The SWDL function is used to change the firmware for the FLASH equipment in order to enhance existing functions.

Fujitsu is developing the FLASH series

SONET/SDH products to enable flexible realization of the requirements described above. **Figure 1** shows an example of a SONET/SDH network application of the FLASH series.

2.2 STM/ATM hybrid system

ATM is an efficient transmission method in which the same physical layer can be used for various ATM services. ATM is expected to become the transmission method for the next generation.

The FLASH 600 ADX supports the ATM cells of SONET/SDH physical layers such as OC-3, OC-12, and OC-48 and the physical layers of DS1 and DS3. The LAN signal of an Ethernet is mapped and switched to the ATM cells and transferred to the fiber of the SONET/SDH system.

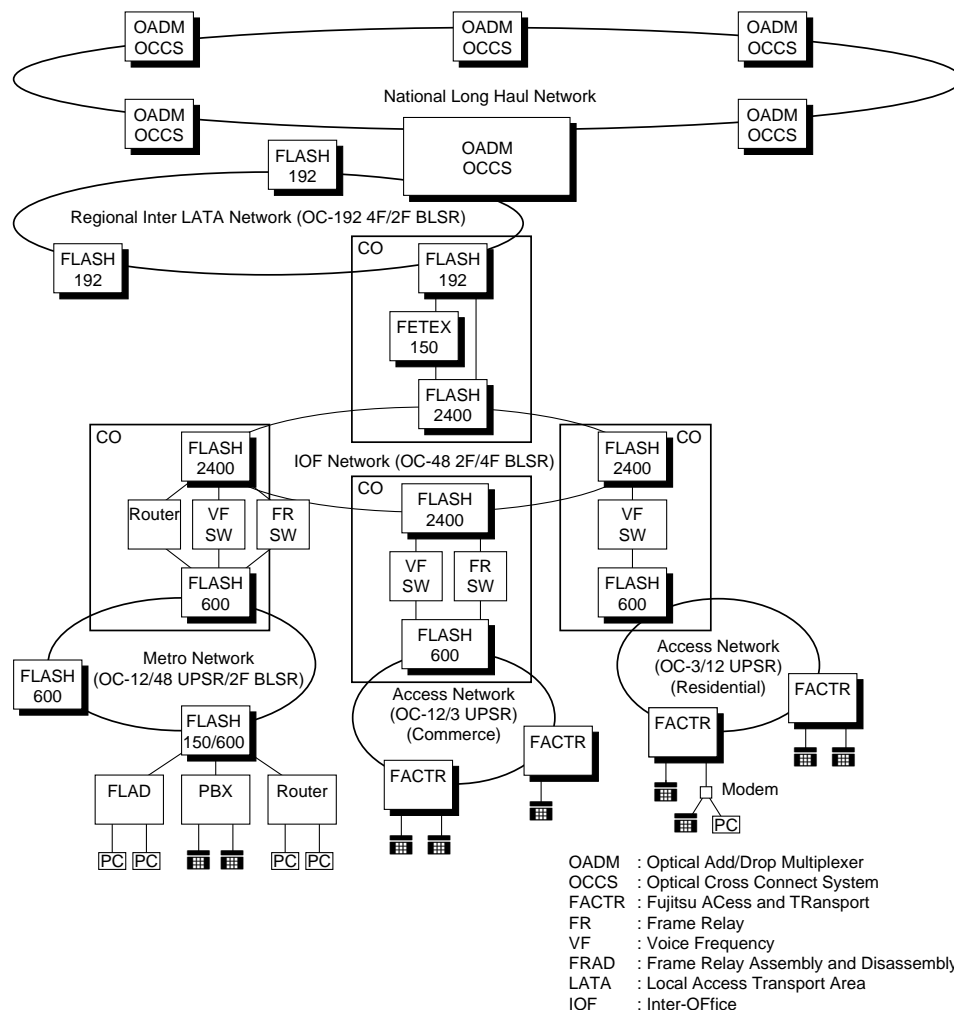


Figure 1
System application for SONET/SDH.

The FLASH 600 ADX supports the Permanent Virtual Connection (PVC) and Switched Virtual Connection (SVC) for the connection of ATM cells and the Simple Network Management Protocol (SNMP) interface for the Management Information Base (MIB) of ATM/LAN management.

2.3 Dense wavelength division multiplexer (DWDM) support

The FLASH series supports the DWDM system with the FLASHWAVE equipment. Narrowband optical plug-ins, which are standardized

to the ITU-T grid, are installed in the FLASH-192 equipment. The FLASHWAVE provides an integrated DWDM optical signal from each narrowband optical signal.

2.4 SONET/SDH FLASH series

Fujitsu's FLASH series was introduced to support the total SONET/SDH system approach. Fujitsu supplies the FLASH-192, FLASH 600 ADX, and FLASH 2400 ADX.

Table 1 lists the system parameters of the FLASH series, and **Figure 2** shows the system

Table 1
System parameters of FLASH series.

Item	FLASH-192	FLASH 2400 ADX	FLASH 600 ADX
Line rate	9953.28 Mb/s	2488.32 Mb/s or 9953.28 Mb/s	622.08 Mb/s or 2488.32 Mb/s
Transmission capacity	129024 telephone channels	32256 or 129024 telephone channels	8064 or 32256 telephone channels
Multiplexing	Positive/negative synchronization, byte interleaving		
Tributary	OC-48 × max.8 OC-12 × max.32 OC-3 × max.128	OC-48 × max.16 OC-12 × max.40 OC-3 × max.80 DS3/EC-1 × max.96	OC-12 × max.16 OC-3 × max.32 DS3/EC-1 × max.36 DS1 × max.168 10 Base-T × max.48 100 Base-T × max.48
Mapping	STS-1 byte interleave multiplexer	DS3 direct mapping STS-1 byte interleave multiplexer STM cell mapping	
Line code	Scrambled-NRZ		
Protection ^{note1)}	2F/4F-BLSR, UPSR, 1+1, 1:N		2F-BLSR, UPSR, 1:N, ATM VP-base protection
Switching scheme	Forced, auto, manual, lock-out		
Switching time	Less than 50 ms (BER exceeds 10 ⁻³ at line rate)		
Supervisory	TL-1 interface		TL-1 interface, SNMP interface
Ambient temperature	0 to 50°C	0 to 50°C	-40 to +65°C
Shelf dimensions W × D × H (cm)	OC-192 TS ^{note2)} : 58.42 × 30.48 × 80.01 (23" × 12" × 31.5") OTS ^{note2)} : 58.42 × 30.48 × 44.45 (23" × 12" × 17.5") RS ^{note2)} : 58.42 × 30.48 × 44.45 (23" × 12" × 17.5")	58.42 × 30.48 × 53.34 (23" × 12" × 21")	58.42 × 30.48 × 44.45 (23" × 12" × 17.5")

note1) 2F-BLSR (Two-Fiber-Bi-directional Line Switched Ring)
4F-BLSR (Four-Fiber-Bi-directional Line Switched Ring)

note2) OC-192 TS : OC-192 Transport Shelf
OTS : Optical Tributary Shelf
RS : Routing Shelf

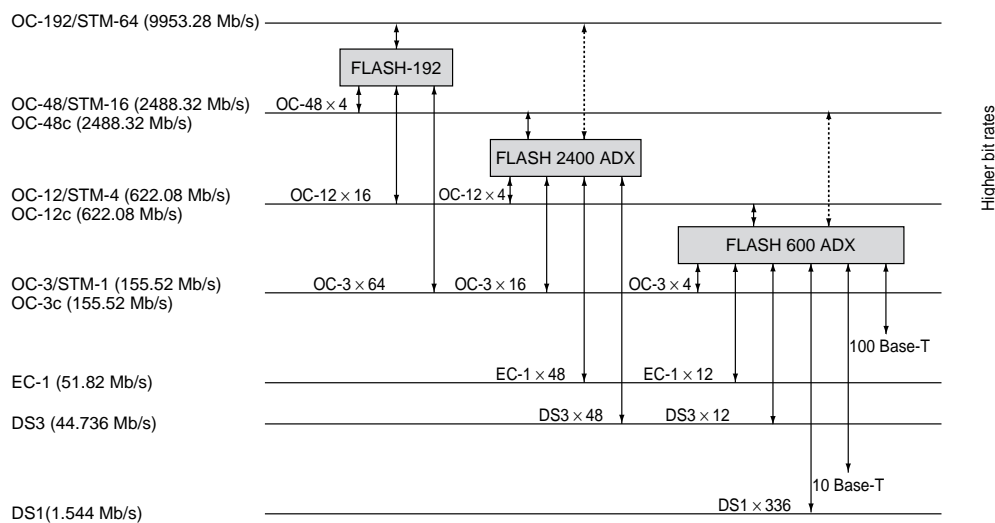


Figure 2
Hierarchy for SONET/SDH FLASH series.

hierarchy. As shown in Figure 2, all SONET/SDH hierarchies can be constructed from a combination of the three types of FLASH systems. An overview of each FLASH system is given below.

2.4.1 FLASH-192

The FLASH-192 is an ultra-high-speed (10 Gb/s) optical transmission system with advanced network survivability. It was introduced in the U.S. market in 1996 for use in the next-generation trunk network.

The main elements of the FLASH-192 are as follows:

- 1) OC-192 1+1/2:0 terminal
- 2) OC-192 2F-BLSR/4F-BLSR
- 3) OC-192 UPSR
- 4) OC-48 2F-BLSR/4F-BLSR
- 5) OC-48/OC-12/OC-3 1+1/2:0 terminal
- 6) OC-48/OC-12/OC-3 UPSR

2.4.2 FLASH 600 ADX

The FLASH 600 ADX is an optical transmission system used primarily in the loop network. It will provide ATM services such as a LAN, Frame Relay, and Cell Relay. Other features of the FLASH 600 ADX include an operating temperature range from -40°C to $+65^{\circ}\text{C}$, compact packaging, and reduced power drain for installation in a cabinet.

The main elements of the FLASH 600 ADX are as follows:

- 1) OC-12/OC-3 1+1/2:0 terminal
- 2) OC-12/OC-3 UPSR
- 3) OC-48 2F-BLSR

2.4.3 FLASH 2400 ADX

The FLASH 2400 ADX is a 2.4 Gb/s optical transmission system used primarily in interoffice and trunk systems. In the future, it will support an ATM function.

The main elements of the FLASH 2400 ADX are as follows:

- 1) OC-48 1+1/2:0 terminal/Linear ADM
- 2) OC-48 UPSR
- 3) OC-48 2F-BLSR/4F-BLSR
- 4) OC-192 2F-BLSR
- 5) OC-3/OC-12 1+1/2:0 terminal
- 6) OC-3/OC-12 UPSR

Detailed explanations of the FLASH-192 and FLASH 600 ADX, including the key technologies, are given in Chapters 3 and 4.

2.5 Operations support

The FLASH series has a gateway interface for interfacing with the Operation Systems (OS). There are two types of gateway interface for the FLASH series. These interfaces use the standard-

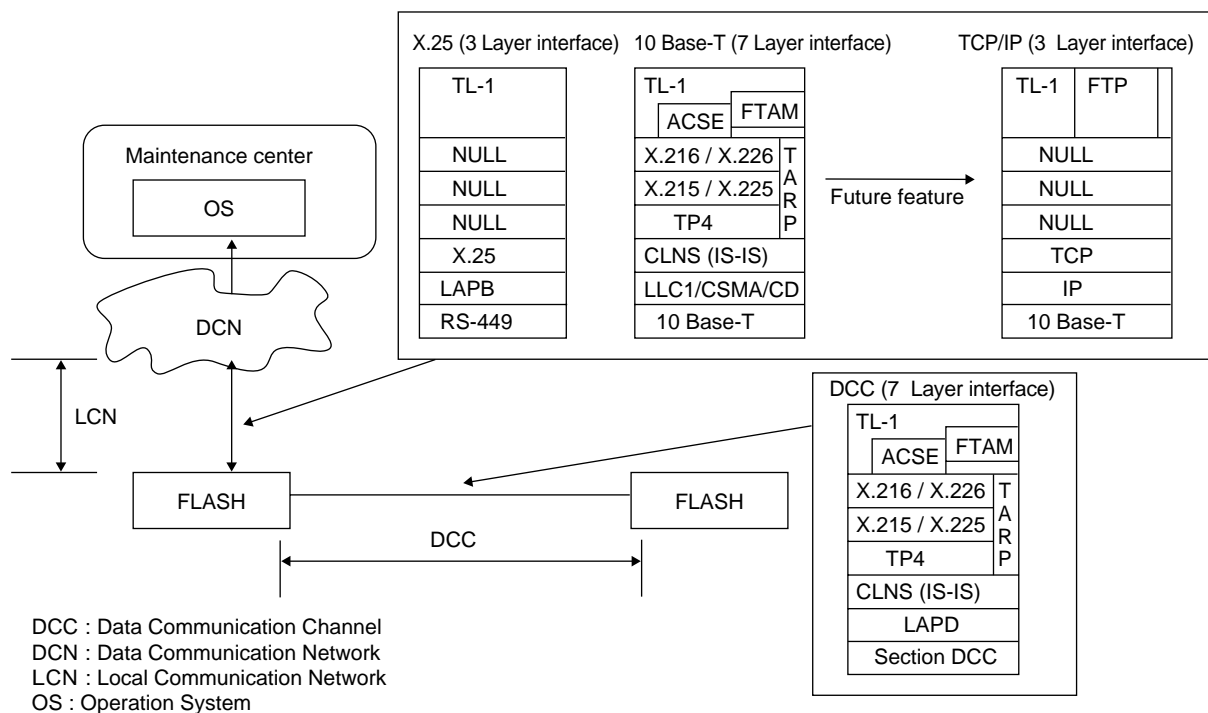


Figure 3
SONET/SDH operation system.

ized protocol of the Open System Interconnect (OSI) stack. Messages for communications are coded using the Transaction Language-1 (TL-1), which is specified by Bellcore. The FLASH series has the following types of electrical interface to connect with the OS:

- 1) 10 Base-T interface
- 2) X.25 interface (RS-449)

However, a TCP/IP interface to enable use of the 10 Base-T interface is planned for the gateway interface in the near future. The FLASH series will also support the TCP/IP interface in the near future.

Figure 3 shows the block diagram for the connection from the OS to the FLASH series.

3. FLASH-192 description

This chapter describes the FLASH-192 in more detail and describes its key technologies.

3.1 Features of the system

Fujitsu introduced the FLASH-192 to the

North America market in 1996. The FLASH-192 is the next generation of SONET/SDH equipment and has a large-capacity 10 Gb/s line interface.

The FLASH-192 consists of three modules:

- 1) Transport complex
- 2) Routing complex
- 3) Management complex

By combining these complexes, the FLASH-192 can support Network survivabilities such as 2F-BLSR, 4F-BLSR, UPSR, and 1+1 terminal.

By making the Routing complex the core, each system application of the 2F-BLSR, 4F-BLSR, UPSR, and 1+1 terminal can be supplied for both line and tributary interfaces.

The cross connect function can be performed by the STS-1 level in the Routing complex. The Management complex controls the overall operation of the FLASH-192 system. The Management complex is accommodated in the OC-192 Transport shelf.

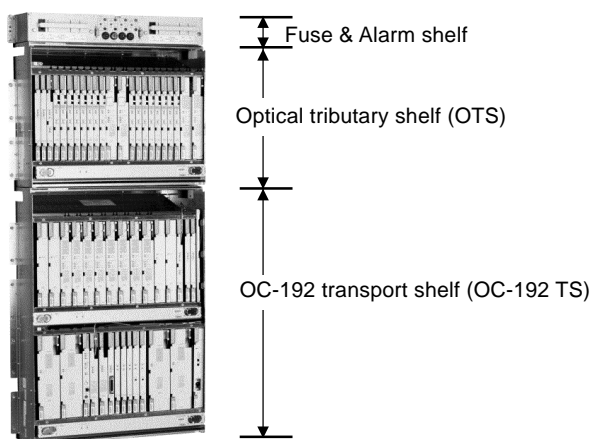


Figure 4
FLASH-192.

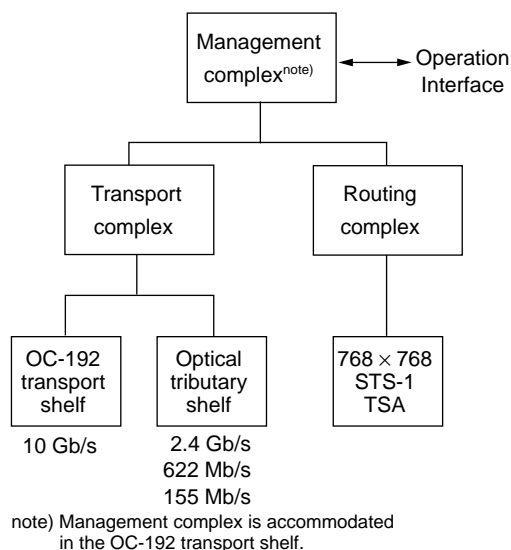


Figure 5
Block diagram of complexes.

3.2 System configuration

The FLASH-192 system consists of three complexes:

- 1) Transport complex : Main traffic (signals)
- 2) Routing complex : Cross connect function
- 3) Management complex : Surveillance, control

Figure 4 shows the front view of the FLASH-192 (OC-192 transport shelf and Optical tributary shelf), and Figure 5 shows the block diagram of each complex.

3.2.1 Transport complex

The Transport complex consists of two types of shelves:

- OC-192 transport shelf
- Optical tributary shelf
- (OC-3 / OC-12 / OC-48 tributaries)

OC-192 transport shelf

The OC-192 transport shelf terminates the 10 Gb/s line interface and demultiplexes the OC-192 signals to 4 x OC-48 signals. The direct OC-48 interface is provided at the OC-192 transport shelf to connect with the other OC-48 equipment. A cross connect with unrestricted Time Slot Assignment (TSA) or an OC-3 / OC-12 tributary are required. The Routing shelf or Optical transport shelf is connected with the OC-192 transport shelf. Standard OC-48 interfaces are used between shelves.

The Regenerator application is provided to use the OC-192 transport shelf. When the Regenerator application is used, no OC-48 interface is installed in the OC-192 transport shelf.

Optical tributary shelf

The optical tributary shelf terminates the OC-3, OC-12, and OC-48 tributary interfaces. An optical tributary shelf can accommodate any combination of tributary types. The optical tributary shelf is connected to the OC-192 transport shelf or the routing shelf by the OC-48 interfaces.

The system applications for the tributary interfaces are as follows:

- OC-3/OC-12/OC-48 1+1/2:0 terminal
- OC-3/OC-12/OC-48 UPSR
- OC-48 2F-BLSR/4F-BLSR

3.2.2 Routing complex

The routing complex is constructed in the routing shelf. The routing shelf supports a 768 x 768 Time Slot Assignment (TSA) function (40 Gb/s capacities). TSA is done by the STS-1 level, and a hairpinning function to and from tributaries is supported.

The interface between the OC-192 transport

shelf and the optical tributary shelf carries the OC-48 optical signals.

3.2.3 Management complex

The management complex controls the overall operation of the FLASH-192 system. It collects the alarm and performance monitoring information of the FLASH-192 and provides it with a provisioning and control function.

The management complex is accommodated in the OC-192 transport shelf.

The ATM cells (OC-3 signal) are used for communications between shelves.

3.3 Key technologies

3.3.1 Forward error correction (FEC) function

For a long haul network, in-line amplifiers are used between the terminals. However, because of the noise of the amplifiers, the bit error rate is inferior, so error correction is required in order to supply a high-quality signal to the customer.

The FLASH-192 supports the in-band Forward Error Correction (FEC). In-band FEC uses the vacant overhead bytes in the OC-192 frame. Another method, out-band FEC, adds the overhead bytes on the outside of the OC-192 frame. (About 7% of the OC-192 bit rates are added.) Out-band FEC is already used in submarine transmission systems. The FLASH-192 will also support out-band FEC in the future.

The FLASH-192 in-band FEC function is described below.

The FLASH-192 provides OC-192 line level FEC for superior error performance and to maximize span lengths.

Each STS-192 frame is divided into three blocks, and each block is divided into 16 sections. The FEC then performs single Error Correction (SEC) sequentially on each of these sections using an $X^{16} + X^{12} + X^5 + 1$ shorted Hamming code.

Figure 6 shows the FEC code mapping for the OC-192 frame.

Using this method, FLASH-192 can improve the OC-192 line BER performance or improve the

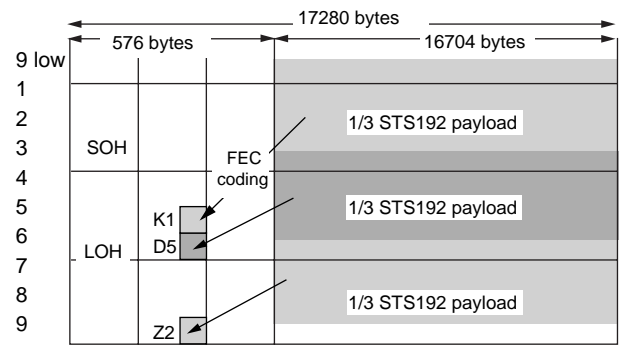


Figure 6
FEC code mapping for OC-192 frame.

Table 2
BER improvements obtained using FEC.

BER w/o FEC	BER with FEC
1×10^{-3}	1.008×10^{-3}
1×10^{-4}	9.673×10^{-5}
1×10^{-5}	2.250×10^{-6}
1×10^{-6}	2.481×10^{-8}
1×10^{-7}	2.506×10^{-10}
1×10^{-8}	2.508×10^{-12}
1×10^{-9}	2.509×10^{-14}
1×10^{-10}	2.509×10^{-16}
1×10^{-11}	2.509×10^{-18}
1×10^{-12}	2.509×10^{-20}
1×10^{-13}	2.509×10^{-22}
1×10^{-14}	2.509×10^{-24}
1×10^{-15}	2.509×10^{-26}

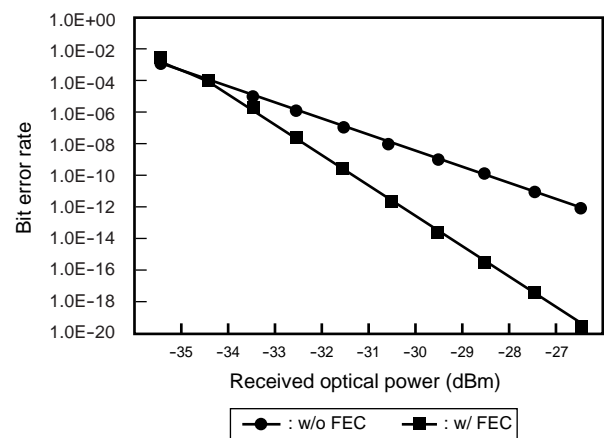


Figure 7
Span budget improvements obtained using FEC (example).

span budget while maintaining the system BER. **Table 2** shows the improvements in the BER that are obtained using FEC. **Figure 7** shows an example of how FEC improves the span budget.

FEC capability is enabled or disabled through software provisioning.

The history of FEC activity (how many errors have been corrected) is stored in registers in the same way as other performance monitoring information. The same features that are provided for SONET performance monitoring, for example, a report & retrieve PM register and threshold provisioning, are provided.

3.3.2 Overhead bytes transparency function

Overhead bytes transparency is required to connect with competitor's equipment. The transparency is required for proprietary usage of the overhead bytes.

The capacity of vacant overhead bytes in the OC-192 frame is about 300 Mb/s. The FLASH-192 can provision the required overhead bytes for transparency to the area of the vacant overhead bytes by using ATM cells.

3.3.3 Routing shelf technologies

- Quad OC-48 interfaces

To realize a compact size, there are four OC-48 interfaces per plug-in for the interfaces between the Routing Shelf and the OC-192 Transport Shelf/Optical Tributary Shelf.

- Low Voltage Differential Signal (LVDS) technology

To realize a compact size and low power consumption for the interface plug-ins, a CMOS ASIC was developed for the 311 Mb/s LVDS signals of the back plane interface.

Figure 8 shows the 311 Mb/s waveform of the LVDS.

4. FLASH 600 ADX description

This chapter describes the FLASH 600 ADX and its key technologies.

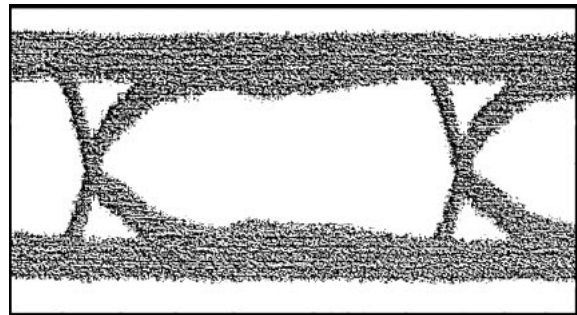


Figure 8
311 Mb/s waveform of LVDS.

4.1 Features of the system

Fujitsu introduced the SONET/SDH equipment to the North America market in 1988 and at that time was the leader of the SONET/SDH market.

Also in 1988, Fujitsu introduced the FLM 50/150, which conforms to the Bellcore standard. This system had a point-to-point configuration, but later Fujitsu introduced the FLM 150 ADM, FLM 600 ADM, and FLM 2400 ADM high-quality, high-survivability ring configurations. With these deployments to the North America market, Fujitsu helped to construct the infrastructure for the SONET/SDH network.

In recent years, because of the increasing demands for data communications, the market requires higher quality and faster data services. To meet these needs, our customers will apply our Asynchronous Transfer Mode (ATM) technology to public networks.

Fujitsu is developing the FLASH 600 ADX to provide both ATM and Synchronous Transfer Mode (STM) functions. The FLASH 600 ADX supplies ATM and STM signals within the same ring network.

4.2 System configuration

The FLASH 600 ADX (Fujitsu Lightwave ATM Shuttle 600M Add/Drop Multiplexer) provides added/dropped STM services such as DS1 and DS3 signals for the current SONET/SDH network and switched/multiplexed ATM services.

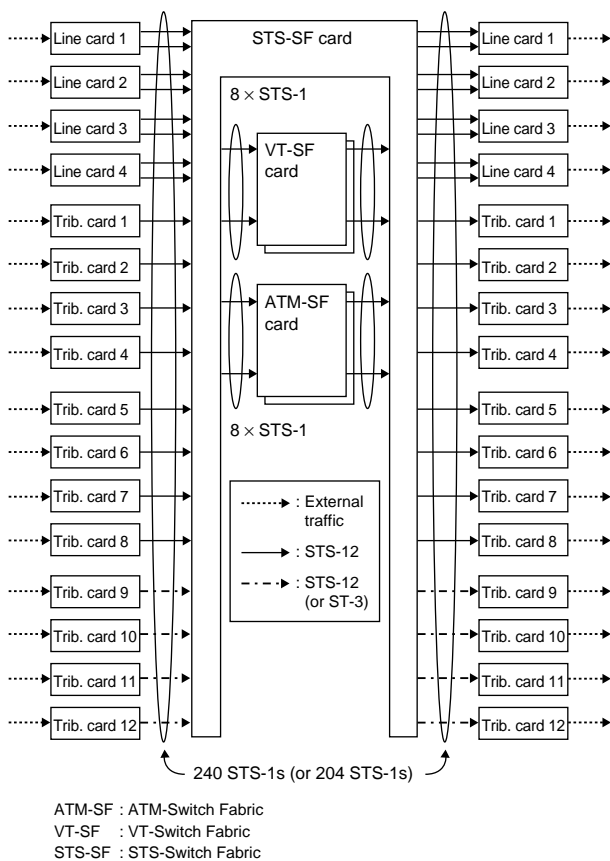


Figure 9
Block diagram of FLASH 600 ADX.

These functions meet the requirements for timely changes of service. The STM and ATM signals are transmitted at the efficiency of the current SONET/SDH network.

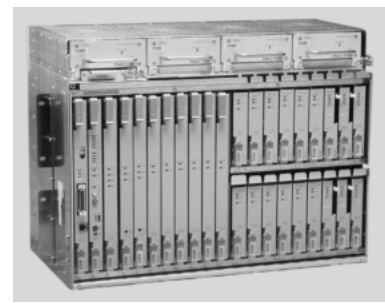
The interface plug-in for the FLASH 600 ADX is based on a 600 Mb/s capacity, and a total of 16 plug-ins are installed. The FLASH 600 ADX has a total throughput of 10 Gb/s.

Figure 9 shows the block diagram for the main traffic signals of the FLASH 600 ADX, and Figure 10 shows the front view of the FLASH 600 ADX.

4.3 Key technologies

4.3.1 Large-capacity technology

Because the FLASH 600 ADX was designed to support 10 Gb/s transmission and to be physically compact, communication between plug-ins had to be done at high speed. The FLASH 600 ADX



FAN (1)		FAN (2)		FAN (3)		FAN (4)	
MC	ATM-SF and/or VT-SF	STS SF	Trib. 7 to 12		Line 3, 4		
			Trib. 1 to 6		Line 1, 2		

MC : Management complex

Figure 10
FLASH 600 ADX.

uses the standard Synchronous Transport Signal - Level 12 (STS-12) 622.08 Mb/s signal between plug-in interfaces. Because of these interfaces, the FLASH 600 ADX supports various interface services and universal slots which are not related to the service interfaces such as the ATM and STM interfaces. Also, to realize a compact size and low-power consumption for the interface plug-ins, a CMOS ASIC was developed for the 622 Mb/s Low Voltage Differential Signal (LVDS) signals of the back plane interface. This ASIC performs Clock / Data Recovery (CDR) in the LVDS interface circuit and eliminates the skew problem between the data and clock of the high-speed signal. Table 3 shows the specifications of the ASIC for the LVDS interface.

Figure 11 shows the 622 Mb/s waveform of the LVDS.

Because the combined STM signals and ATM-cell signals are required for the STS level signals, the Virtual Tributary (VT) of the SONET/SDH signals and switch, and the cross connect for the ATM cells, two large-size ASICs were developed for the cross connect function of STS levels. These ASICs support the following functions:

Table 3
Specifications of ASIC for LVDS interface.

Items	Specification
High-speed interface	622.08 Mb/s 155.52 Mb/s
Low-speed interface	77.76 Mb/s
Number of ports	2
Package	QFP128
Power consumption	1.3 watts

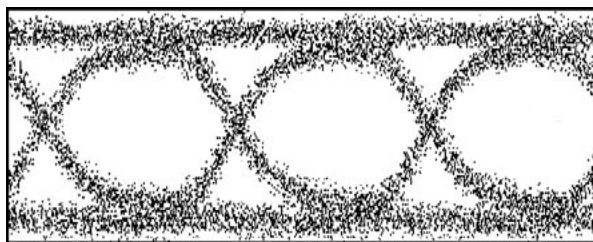


Figure 11
622 Mb/s waveform of LVDS.

- 1) An STS level cross connect function between interface plug-ins
- 2) An STS level Add/Drop function for access of VT and ATM levels.

These two ASICs were developed for the 10 Gb/s × 10 Gb/s Time Slot Interchange (TSI) and for the alarm and performance monitor for all STS path signals.

The switching fabric cards (STS, VT, and ATM) are duplicated independently, and the STS-SF card has the STS TSI function, which provides a 30 Gb/s throughput.

4.3.2 Hybrid transmission

From now on, to ensure low-cost network operation and a good transmission efficiency, STM and ATM will need to coexist. The FLASH 600 ADX provides DS1 traffic based on the SONET frame and the cross connect for VT signals and ATM cells. Each signal is based on a 2.5 Gb/s capacity, and a flexible slot is provided for customer services. The switching fabric group will be expanded to enable any combination of STS-1, VT, and ATM-cell signals up to a maximum

capacity of 10 Gb/s.

4.4 ATM support

4.4.1 Transmission function of ATM service

In the ATM method, the same physical layer is used for various ATM services. ATM is expected to become the transmission method for the next generation. The FLASH 600 ADX supports the ATM cells for SONET/SDH physical layers such as OC-3, OC-12, and OC-48 and the physical layers of DS1 and DS3. The LAN signal of an Ethernet is mapped and switched to the ATM cells and transferred to the fiber of the SONET/SDH system. The FLASH 600 ADX supports the Permanent Virtual Connection (PVC) and Switched Virtual Connection (SVC) for the connection of ATM cells and the SNMP interface for the MIB base for ATM/LAN management.

4.4.2 ATM survivability

Reliability is extremely important in a public network. In addition to the currently provided Uni-directional Path Switched Ring (UPSR) and Bi-directional Line Switched Ring (BLSR) survivability methods for the STM signal, in the near future, ring networks will also require ATM survivability. The FLASH 600 ADX supports ATM Virtual Path (VP) switching, which is almost the same as UPSR switching. When communication fails, protection switching is done by the Operation, Alarm, and Maintenance (OAM) cells for the appropriate VP signal.

4.4.3 Application for IP packet switching

The FLASH 600 ADX will supply Internet Protocol (IP) packets under the current network because demand will increase for the various services. IP will also be provided in future enhancements. The FLASH 600 ADX will support SONET/SDH mapping for IP packets and transmission. The switching function of the packet levels will also be supported in the FLASH 600 ADX.

5. Conclusion

Fujitsu has developed and delivered the FLASH-192 and FLASH 600 ADX equipment, which conforms to the SONET/SDH specification. Also, Fujitsu is currently developing the FLASH 2400 ADX.

The FLASH architecture will have enhancements to conform to future standards. The basic specifications and technologies are common all over the world. Therefore, Fujitsu will provide the international market with SONET/SDH products. Accomplishing this requires the mass production of gigabit optical LSIs.

Fujitsu intends to promote a total SONET/SDH approach in line with its goal of becoming a world leader in the field.

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He joined Fujitsu Laboratories Ltd., Kawasaki, Japan in 1985 and has been engaged in research and development of digital optical fiber transmission systems and their ASICs. Since 1989, he has been with Fujitsu Ltd., Kawasaki,

Japan. Currently, he is working on high-speed optical network systems and ASICs, including a highly-stabilized digital PLL ASIC, a BLS-Ring transmission system, and a 10 Gb/s optical transmission system.

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