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# Photonic Networking Using Optical Add Drop Multiplexers and Optical Cross-Connects

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**The photonic network will enable the construction of high-capacity and flexible optical communication systems for the future data-centric era. Optical add drop multiplexers (OADMs) and optical cross connects (OXCs) along with already mature DWDM systems are key technologies for photonic networking. Prototype systems of OADMs based on the acousto-optic tunable filter (AOTF) and OXCs based on PLC optical switches have been demonstrated.**

**This paper provides a perspective of the latest optical path layer technologies.**

## 1. Introduction

In the 21st century, there will be an explosive growth in the amount of information being transmitted by digital services such as electronic commerce, software distribution, and digital video/music distribution services. The capacity required to handle all this information will be provided using new communication technologies. IP/ATM and photonic networking are key-enablers for realizing terabit capacities and effective and reliable use of networks. Current transport technologies based on the SONET/SDH format are already in wide use in today's networks. The transport network has a layered structure as defined by the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T). It consists of a circuit, transmission media, and path layer. The maturity of OC48, OC192, and extremely dense WDM forces us to rethink the strategy for cost-efficient bandwidth management using these layers. The introduction of an optical path layer with high bit rate TDM pipes multiplexed by DWDM which can be managed by OADM and OXC will be effective for overall network efficiency.[1] In the ring architecture, an OADM can be introduced to make efficient use of network capacity, network protection, wavelength routing, and many more features. In the mesh architecture, an OXC could provide the scalability, modularity, and transparency required in the network. In addition, photonic networks based on OADMs and OXCs will provide openness and transparency in future networks to accommodate various client signals with different bit rates and formats (e.g., SONET, SDH, ATM, and IP) efficiently and to forward the client signals transparently to end users.

This paper provides a perspective of the latest optical path layer technologies. Some key advancements in the OADM architectures using acousto-optic tunable filters (AOTF) will be described along with the concept of optical path protection. Also, optical path cross connect architectures will be discussed along with the key features required for practical use of this technology.

## 2. Optical Add Drop Multiplexer (OADM)

OADM technology is used to cost effectively access part of the bandwidth in the optical domain being passed through the in-line amplifiers with the minimum amount of electronics. OADM can be used in the static as well as dynamic mode. **Table 1** shows the migration scenarios of OADM. In passive OADM, the add and drop wavelengths are fixed beforehand. In dynamic mode, the OADM can be set to any wavelength after installation. Passive OADM is currently being used in networks with WDM systems. The technologies used to accomplish passive OADM are thin-film interference filters, fiber gratings, and planar waveguides. The optical characteristics such as the insertion loss and the inter-band and intra-band crosstalk are well understood for each of these technologies when used in a passive OADM application. Dynamic OADM has the advantages of better cost-effectiveness and flexibility than passive OADM because it can select any wavelength by provisioning on demand without changing its physical configuration. A smooth migration from passive to totally reconfigurable and dynamic OADM will be necessary. Dynamic OADM is classified into two generations. The second generation is mainly applied in a linear configuration without an optical path protection function. The path protection function is supported by electrical ADMs. Finally, the third generation will be applied in a ring configuration to provide optical layer path protection based on the 4-fiber Bi-directional Line Switched Ring (BLSR) and other protection schemes.[2)]

Regarding the architecture of dynamic OADM configurations, there are two types. One is the SW type with a back-to-back multiplexer/demultiplexer, and the other is the AOTF type. **Figure 1** shows these configurations. One of the technical difficulties in using the SW type for OADM is that for $n$ channels in a WDM system, an $n \times n$ optical switch will be required on the drop and add sides to accomplish a dynamic capability. This can be extremely expensive and cumbersome. Other problems such as channel passband narrowing due to concatenation of multiplexers/demultiplexers for a channel spacing of 0.8 nm or less can also create major problems in a long-distance network.[3)] The AOTF type holds a lot of promise for providing a cost-effective solution for a static as well as dynamic OADM and presents no passband narrowing problem. We have therefore been developing dynamic OADM systems using AOTF.

Table 1
Migration of OADM.

| Generation | I | II | III |
|---|---|---|---|
| Configuration | Passive OADM | Dynamic reconfigurable OADM | |
| Add/Drop wavelength Number of wavelengths | Fixed | Settable by provisioning | |
| Connection to electrical nodes (client) | Manual change of fiber connections | Automatic change of connections by optical SW with provisioning | |
| Network protection | SONET/SDH APS | | Optical layer APS |
| Network architecture | Linear | Linear | Linear, ring<br>OBLSR/OBPSR |
| Key devices | Fiber grating<br>Dielectric filter | Optical SW, AOTF<br>Tunable wavelength LD | |

## 2.1 Acousto optic tunable filter (AOTF) configuration

**Figure 2** shows the device configuration of an AOTF developed by Fujitsu.[4)] The device is fabricated on lithium niobate ($LiNbO_3$) and is composed of an inter-digital transducer (IDT), optical waveguide, thin-film surface acoustic wave (SAW)

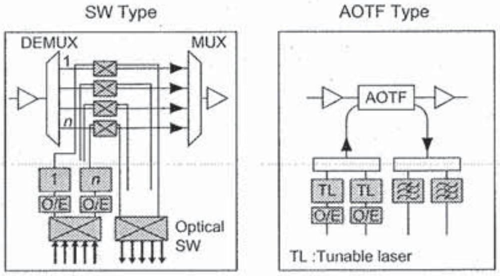

Figure 1
SW and AOTF types of OADM architectures.

guide, and polarization beam splitters (PBSs). The incident light is propagated over the optical waveguide and divided into perpendicular components (TE/TM) by the first PBS. An acoustic wave is generated by applying an RF signal to the IDT. This acoustic wave travels through the SAW guide and causes a periodic modulation of the refractive index of the optical waveguide. This change of refractive index induces TE-TM or TM-TE conversion for only the drop wavelength. The drop wavelength corresponds to the applied RF frequency and becomes perpendicular to the incident light. The second PBS is then used to separate the drop wavelength from the incident light. An AOTF can not only drop a single wavelength but also multiple wavelengths simultaneously. By changing the number of RF signals and their frequencies, we can control the number and frequencies of the drop wavelengths. There are no moving parts in the AOTF, and it offers high-speed wavelength tuning that can be done sequentially or randomly based on the applied RF frequency. Although the insertion loss of AOTFs has been relatively high and the sidelobe suppression has been poor, recent advancements have significantly improved both of these characteristics and allow optimal network efficiencies in the photonic layer unit (SAU).

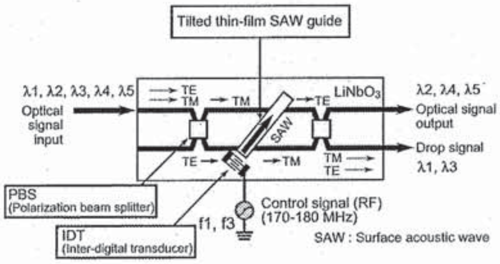

Figure 2
Configuration of AOTF.

**Figure 3** shows WDM signal separation using an AOTF. By using two AOTFs, we were able

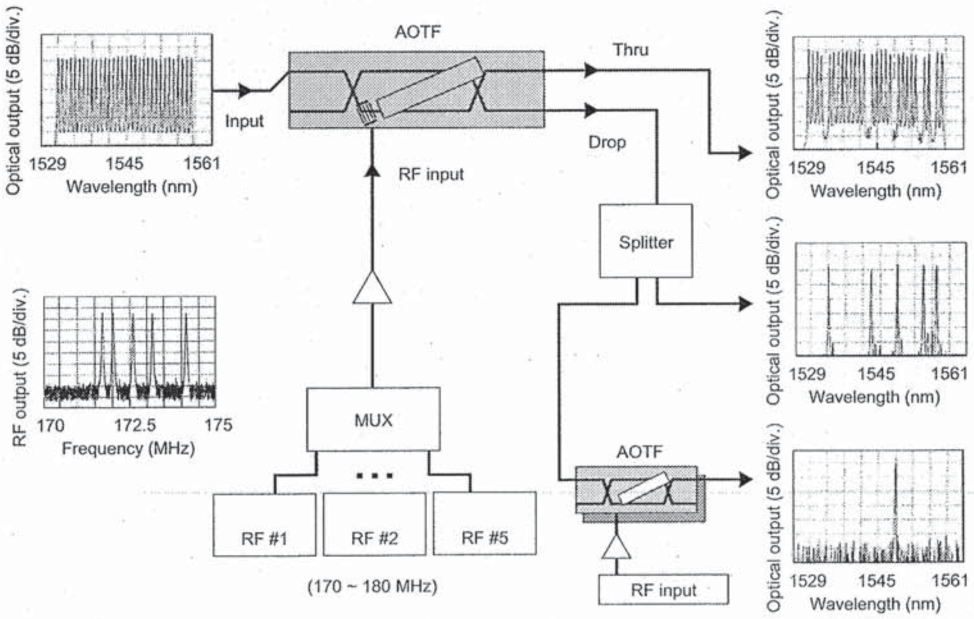

Figure 3
Wavelength selection by AOTF.

to extract any wavelength among 32 wavelengths separated with a 0.8 nm channel spacing. The first AOTF dropped five wavelengths simultaneously and passed the remaining 27 to the through port. Then, the second AOTF extracted the desired wavelength from the five dropped ones. This method provides sufficient adjacent channel crosstalk suppression.

### 2.2 OADM design considerations

To maximize the effectiveness of an OADM, the functions listed in **Table 2** have to be considered. Our system was designed according to the following five main considerations:

1) In the case of an OADM node with AOTFs, an AOTF can be used instead of an $n \times n$ switch to retrieve individual or multiple channels. Also, transponders (O/E, E/O, optical modulators) with tunable lasers can be used on the add side to provide the dynamic capability. In this case, the OADM can support random selection of wavelengths.
2) Our system can support a drop-and-continue or broadcast feature by using a signal tap component within the OADM node. This function will be useful for the configuration of dual-hubbing in a multiple ring connection.

Table 2
Functions of OADM.

| Functions | Issues |
|---|---|
| Wavelength MUX/DMUX | •Maximum number of wavelengths: 16, 32, 64, 128...<br>•Number of add/drop wavelengths |
| Wavelength cross-connect (λ SA: λ slot assignment) | •Add wavelength: Fixed/Settable<br>•Drop wavelength: Fixed/Settable<br>•Through wavelength: Fixed/Settable (λ SI: λ Slot interchange)<br>•Broadcast (Drop and Continue) |
| Inter-office IF | •Transmission fiber: SMF/DSF/NZ-DSF, span, number of spans<br>•Inter-working for maintaining survivability: SONET/SDH APS, optical SNR |
| Intra-office IF | •OC192/c, OC48/c, Asynchronous signal, G-Ethernet, 100 BaseF<br>•Inter-working for maintaining survivability |
| Management and control | •Wavelength control, Performance monitoring, Output level control, wavelength path trace<br>•Transferring supervisory channel: OSC (optical supervisory channel) |

3) Our system can support a function of optical layer protection such as the 4-fiber Bi-directional Line Switched Ring (BLSR). **Figure 4** shows the OADM node configuration of an optical self-healing ring. This configuration consists of four fibers for two bi-directional lines, dual nodes (work and protection node) for each direction, optical span SWs, and optical ring SWs. Protection line and optical span SWs are used during OADM equipment failures and fiber breaks on the work side. Optical ring SWs are prepared to loop back during fiber breaks on both the work line and the protection line. In addition, this system can monitor parameters of optical signals such as the optical power, wavelength, number of wavelengths, and optical SNR using a built-in optical spectrum analyzer unit (SAU).[5]
4) It is clear that by using AOTF-based OADM, multi-channel access can be easily and cost effectively accomplished. Multi-channel drops can be fed into a simple splitter/coupler, after which multi-channel tributary interfaces can be used to feed the signals into a subtending ring.

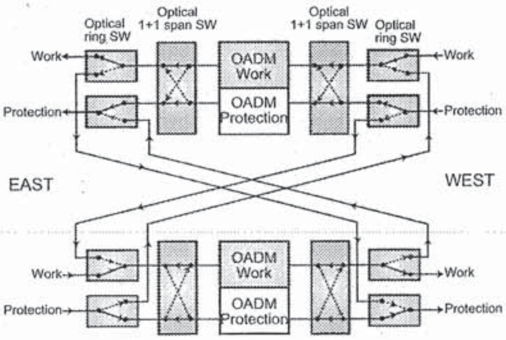

Figure 4
OADM node configuration for optical self-healing ring.

5) Our system can support a Bellcore standard 1510 nm OSC channel for retrieval of alarms and other supervisory information. These OADM nodes can support express pass-through of the OSC channel.

### 2.3 Prototype OADM system

**Figure 5** shows the configuration of a prototype OADM system using an AOTF, and **Table 3** lists its specifications. The OADM system consists of an OADM shelf, Tributary shelf, and Wavelength bank shelf. This system can accommodate 32 wavelengths at 10 Gb/s with a 0.8 nm channel spacing (line capacity: 320 Gb/s) and add/drop any four wavelengths. The AOTF in the OADM shelf divides input WDM signals into drop and through signals. The drop signals are passed through the AOTFs in the Tributary shelf to extract the desired wavelengths, which are then received by each electrical node. In the add process, the wavelength bank is used instead of tunable LDs. In the Wavelength bank shelf, LDs having the same wavelengths as the wavelengths used in the line are prepared in advance. These wavelengths are combined and provided to each optical external modulator. The modulators are driven by the add signal received from the O/E. The desired wavelength is selected after modulation by an AOTF and launched out of the line as the add signal. As a result, the wavelength of the add signal is converted to the desired wavelength in the OADM.

The prototype OADM system is shown in **Figure 6**. This system was demonstrated at Supercomm'98 in Atlanta as the world's first totally reconfigurable, dynamic OADM.

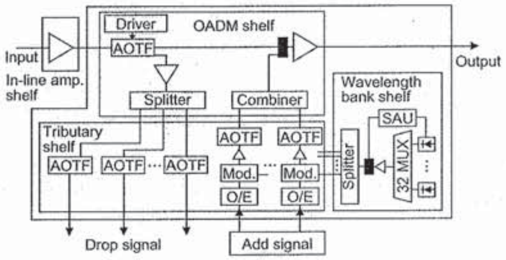

Figure 5
OADM configuration using AOTFs.

Table 3
OADM system specifications.

| Items | Features | Remarks |
|---|---|---|
| Architecture | AOTF-based free wavelength add/drop | Wavelength conversion |
| Line capacity and wavelength | 320 Gb/s<br>10 G × 32 w | Compatible with FLASHWAVE320G |
| Add/drop capacity wavelength | 40 Gb/s<br>10 G × 4 w | 8 w (max.)<br>32 w (in future) |
| Channel spacing | 100 GHz | ITU-T grid |
| Optical path rates | 10 Gb/s, 2.5 Gb/s | Transparent |
| Protection | — | Upgrade to optical BLSR |

## 3. Optical Cross-connect System

To realize efficiency and transparency in the optical network, wavelength grooming and routing functions for each client signal and optical path supervising functions such as performance monitoring and path tracking must be provided. The key element for providing these functions is the optical cross-connect (OXC) system.[6]

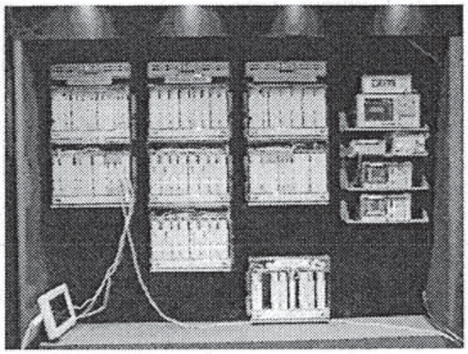

Figure 6
Prototype OADM system at Supercomm'98 in Atlanta.

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