SEAMLESS OADM FUNCTIONALITY FOR SUBMARINE BU

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Abstract: With the joint effort from component and system vendor, a seamless optical add/drop multiplexer (OADM) using dielectric thin-film filters (TFF) modules now is available for submarine cable applications. It is simple in construction and highly reliable, and is capable of adding or dropping one to several consecutive channels (up to 20% of total) arbitrarily selected. Its maximum insertion loss for trunk traffic is < 1 dB, and no guard band loss for every OADM Branching Unit (BU) in concatenated scenario. This paper describes the characteristics of a single 1-skip-0 and 8-skip-0 OADM BU with 100 GHz spacing and presents an experimental investigation of optical transmission through cascaded OADMs at 40-Gb/s rate.

1. INTRODUCTION

In accordance with the traffic and route diversity requirement, many submarine cable systems being planned today include one or multiple branching units (BU) with optical add/drop multiplexers (OADMs) to allow a small number of wavelengths or channels are selectively dropped and/or added from/into the main trunk cable. The typical way in industry to provide OADM functionality is to connect fiber Bragg gratings (FBGs) to optical couplers [1] or optical circulators [2]. In such configuration, express and add/drop channels will incur ~4.0dB of loss with each pass through a single OADM, and therefore additional amplification is need. A second dominant method for making an OADM is to use thin-film filters (TFF). Due to the non-ideal shape of the edges of existing TFFs, such OADMs generally have a guard band of a few hundreds of GHz over adjacent channels [3]. This results in a capacity loss of > 5% from single OADM BU and reduces their applicability in the concatenated scenario.

In view of both loss and cost advantages of TFF OADM, we collaborate with the component vendor and develop high reliable “N-skip-0” TFFs. Using these filters enable the add/drop of up to eight consecutive channels with 100-GHz spacing without affecting the adjacent channels, that is no guard band is required.

The “N-skip-0” TFFs are designed by JDSU based on their advanced thin film deposition techniques and mature laser welding platform used for terrestrial thin film devices, already deployed in the field with more than two million units over ten years. The devices themselves demonstrate ultra-low loss and higher isolation characteristics. They are subjected to a series of environmental and mechanical stress tests. The testing results ascertain these filters can fully meet the desired performance and reliability requirements for submarine applications.

In this paper we present simple, reliable and low-loss 100-GHz 1-skip-0 (1s0) and 8-skip-0 (8s0) TFF-based OADMs, and demonstrate a seamless optical transmission through two cascaded OADMs on a 1100-km 40-Gb/s laboratory system.

2. OADM ARCHITECTURE AND FEATURES

The basic configuration we use for TFF-based OADM is shown in Figure 1. It consists of two pairs of identical three-port TFFs spliced together to form a four-port module. The two cascaded filters on the top achieve the optical dropping and adding, respectively, and simultaneously direct express channels from the input to the output ports. The bottom left and bottom right filters are optional, depending on practical applications. They can act as residual cleanup filters for drop and add channels. Additionally they are able to provide the add-to-drop loopback for dummy lights, which may be transmitted with added service channels to maintain their transmission performance in repeatered branches [4].

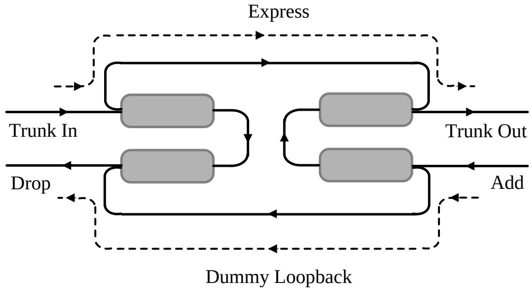


Figure 1: TFFs based OADM configuration

By selecting the passband of TFFs, this OADM module is capable of adding and dropping any single channel or a few of channels without guard band over the adjacent channels. Figure 2(a) presents the transmission characteristics of a 100-GHz 8s0 module. This module has an insertion loss of ~0.7dB and extremely low spectral ripple for through channels. The through-port isolation of dropped channels is ~35 dB. The limit comes from the imperfect transmittance appearing near 1546.9 nm, rather than the adjacent-channel isolation which has a value of above 40 dB. From trunk in to drop ports or add to trunk out ports, good in-band amplitude flatness and sharp rejection characteristics are achieved. The insertion losses for both drop and add channels are < 1.0 dB. The passband ripple is ~0.5 dB peak-to-peak. The isolation on through channels is above 50 dB.

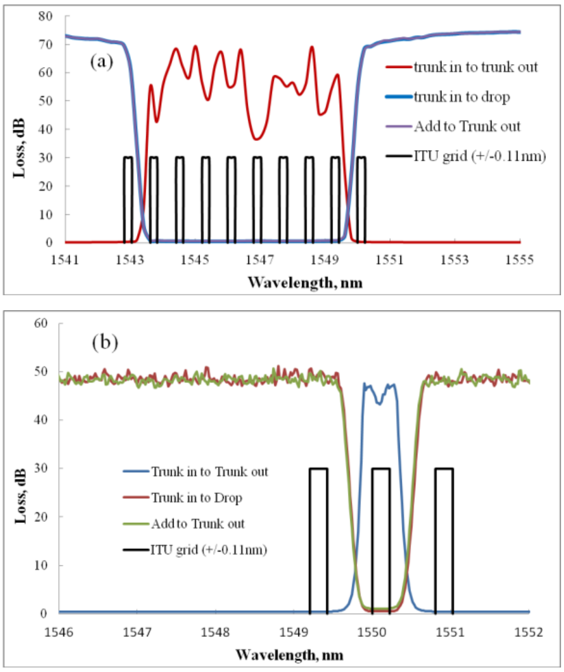


Figure 2: Loss spectra of OADM modules (a) 100GHz 8s0 (b) 100GHz 1s0

A 100-GHz 1s0 module with an add/drop channel contiguous to 8s0 module is produced a well. Figure 2(b) presents its insertion loss spectrum between different ports. The maximum loss for express, drop and add channels are 0.5dB, 0.7dB and 1.1dB, respectively. The isolations for both dropped channel and express channels are over 40dB.

The above two modules represent the maximum and minimum capability of our TFF-based OADMs supporting 100-GHz add/drop without the necessity of guard bands. This means they are able to meet the requirements on submarine OADM BU in most scenarios.

At present the overall OADM BU is ready for commercial use, as the different reliability tests at the various assembly levels have been successfully completed.

3. SYSTEM PERFORMANCE

We perform an experimental investigation of optical transmission through above 1s0 and 8s0 OADMs in cascade at 40-Gb/s rate to ascertain the seamless add/drop function and performance. Figure 3 shows the simplified experimental setup. The main trunk is 1165 km in length with 12 erbium-doped fiber amplifiers (EDFAs), 13 spans of hybrid fibers (LS+, L1000 and standard G.652 fiber) and two OADMs located at 385 km (1s0) and 475 km (8s0), respectively. A 3dB coupler is incorporated just before the first OADM to split the signals into two paths: one path is for the traffic continuing to propagate along the link, and the other path is used for directing traffic into the add path of the second OADM to emulate a repeatered branching link connected to station D. The EDFA output power is +16 dBm. Taking losses of two OADMs, 3-dB coupler, splices/connectors into account, the span loss is about 20 dB in average. Note that we put the focus on the performance of the OADMs, therefore, no optimization is made on the link dispersion design.

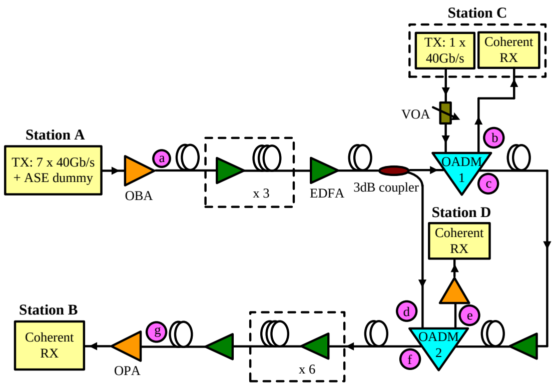
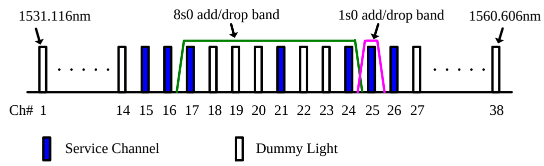


Figure 3: Transmission experimental setup

In Station A, 7 laser channels carrying 40 Gb/s PDM-BPSK modulation signal are multiplexed with 31 amplified spontaneous emission (ASE) dummy lights at 100-GHz spacing. Figure 4 shows the distribution of 7 service channels and their wavelengths. Generally these channels are allocated in either the center or the edges of the add/drop passband, where the isolation is worst. After amplification by an erbium-doped fiber amplifier (EDFA), i.e. OBA, the combined 38 channels over the wavelength range of 1531.116 nm to 1560.606 nm are launched into the transmission fiber. At the first OADM channel 25 centered at 1550.12 nm is dropped and received in Station C. Station C transmits a new 40Gb/s signal at the same wavelength, which will be inserted into the main trunk through the first OADM, as shown in Figure 3. At the second OADM channels 17 ~ 24 (1543.73nm ~ 1549.32 nm) are fed into the drop-path towards Station D where they are preamplified, demultiplexed and received. At the same time, the add path is loaded with the signal split from the main trunk. In consequence, 8 channels are re-inserted into the main trunk through the second OADM. At the end of the main trunk all the channels passing-through and reinserted are amplified by OPA and received in Station B.



Ch #	Frequency(THz)	Wavelength(nm)	
15	194.4	1542.14	Pass Through
16	194.3	1542.94	
17	**194.2**	**1543.73**	OADM2 Add/Drop
21	**193.8**	**1546.92**	
24	**193.5**	**1549.32**	
25	**193.4**	**1550.12**	OADM1 Add/Drop
26	193.3	1550.92	Pass Through

Figure 4: Wavelength allocation of service channels

Firstly, the line is pre-emphasised when two OADMs are removed. Pre-emphasis is performed by changing individual channel launch power in Station A to equalize optical signal-to-noise ratio (OSNR) for all 38 channels at the end of main trunk. Figure 5(a) depicts the input spectrum post pre-emphasis (without OADMs). Q-factor measurements for 7 service channels are made in Station B over a time period of > 4 hours. The mean Q factors are shown in Figure 6 (triangle markers).

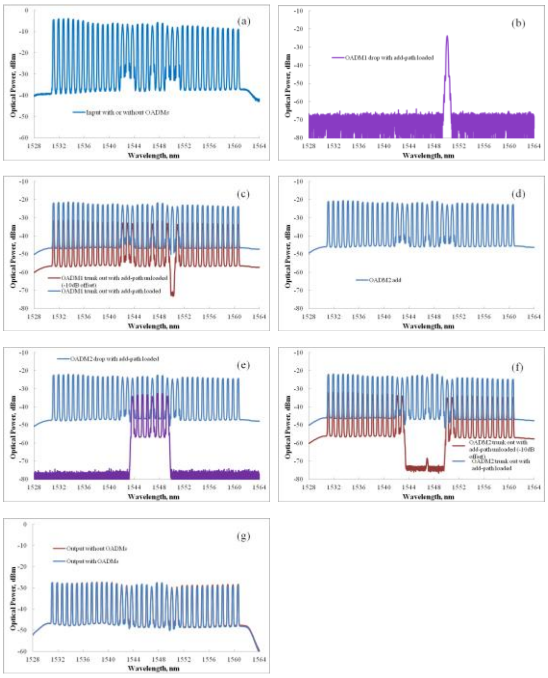


Figure 5: Optical spectra measured in different positions of the link

Then two OADMs are incorporated into the link. Re-adjustment of pre-emphasis is not done in Station A. At the first OADM, 1550.12nm wavelength channel is dropped and sent to Station C (see Figure 5(b)). At the same time Station C launch a new add signal, whose power is controlled to keep the same level as the dropped channel. Figure 5(c) presents the optical spectrum measured at the output port of the first OADM with new channel added (top line). As comparison the spectrum without the addition of the add channel is shown in Figure 5(c) as well (bottom line). At the second OADM, 8 channels including signals and noise in the add/drop waveband, are dropped as a whole. When the add path is unloaded, only these dropped channels (see bottom line in Figure 5(e)) are sent to Station D. At the output of the second OADM, all the through channels are evenly attenuated, while leaving empty channel slots for dropped channels (see bottom line in Figure 5(f)). The drop extinction agrees well with the isolation of the 8s0 OADM module. Due to leakage from the dropped channel operated at 1546.92 nm there appears a residual component at the bottom of the empty block (see bottom line in Figure 5(f)). However, the channel isolation is sufficient to insure the intraband crosstalk on the added channel is negligible. When the add input of the second OADM is loaded with split signal (see Figure 5(d)), the reinserted channels fill the empty channel slots (top line in Figure 5(f)) and the incidental dummy lights are loopbacked to the drop path (top line in Figure 5(e)). No observable changes on the express channels are found through both the first and the second OADMs. Finally, all express and added channels are received in Station B. The optical spectrum, as shown in Figure 5(g), overlaps with previous measurement (red line) without OADMs. Note that to identify two traces in Figure 5(c), (e) and (f) clearly, power level offsets labelled are made deliberately.

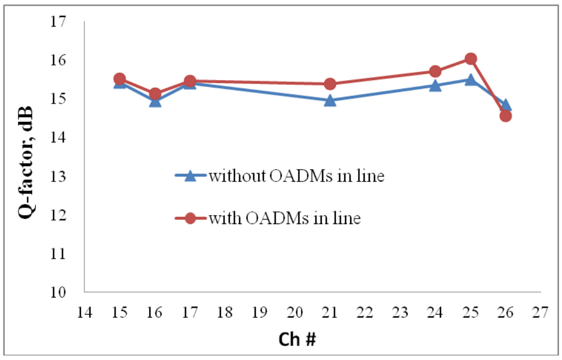


Figure 6: Q-factor performance for service channels with and without OADMs

The mean Q-factor is measured in Station B, C and D. For the drop channels, Q is sufficiently high (> 18) to be able to achieve error free. For the added and pass-through service channels, the results are shown in Figure 6 (circle markers). As compared with the baseline case without OADMs, no penalty is observed for all channels.

4. CONCLUSION

Low through loss (< 1dB), high isolation from dropped channels (> 35dB) and highly reliable 100-GHz 1s0 and 8s0 OADM modules are presented. These OADM modules can accommodate an average add/drop traffic ratio of up to 20% without express capacity loss. The transmission of 40 Gb/s PDM-BPSK signal through two cascaded 1s0 and 8s0 OADMs is demonstrated. No penalty is introduced as compared with the baseline case without OADMs.

As submarine systems have progressed toward 50-GHz and even narrower channel spacing, the development of 50-GHz 4-skip-0 thin film filter, that enables the add/drop of consecutive four signal wavelengths with 50-GHz spacing, has been completed. At present the overall performance of 50-GHz 4-skip-0 OADM module is under evaluation.

5. REFERENCES

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