ACTIVE GAIN SHAPE EQUALIZATION OF SUBMARINE NETWORKS USING WSS ROADM

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Abstract: WSS ROADM is favored by the market for its performance advantages in flexible wavelength configurations and is becoming an integral part of submarine cable systems. The wavelength multiplexing and de-multiplexing between different fiber links can be achieved by WSS ROADM. In a submarine cable system using WSS ROADM, when an abnormal loss occurs in a submarine cable link that enters the WSS ROADM (for example, cable maintenance increases insertion loss or Repeater pump failure causes output optical power to plummet), the output spectrum of the WSS ROADM will no longer be balanced, causing system performance degradation. Using the active gain shape equalization function of WSS ROADM, the spectral spectrum can be effectively adjusted to significantly improve the performance. This feature also enables WSS ROADM to function as SEQ (shape equalizers) and TEQ (tilt equalizers), which is critical for long fiber links.

This paper will experimentally study the impact of abnormal loss scenarios, such as cable maintenance and repeater pump failure on the performance of submarine cable systems using WSS ROADM. We will show that the performance degradation of the submarine cable system can be recovered and maintained using WSS ROADM's active gain shape equalization function.

1. INTRODUCTION

The optical add/drop multiplexer branch unit (OADM BU) is usually used to provide the specific optical wavelength with add/drop function required in the submarine system configurations at multiple landing points [1]. Its basic function is to drop the wavelengths from the optical channel to the branch station from the trunk optical fiber, and add the wavelengths to the other station at the same time without affecting the traffic transmission of other wavelength channels. OADM can be classified into fixed OADM (FOADM) and reconfigurable OADM (ROADM).

FOADM BU requires that all the bandwidth of each landing station be pre-determined and allocated during the initial planning of the submarine cable system. Therefore, FOADM BU cannot meet the flexible needs of customers for network dynamic reconfiguration.

The ROADM BU provides flexible connectivity between multiple landing sites, and is flexible enough to accommodate the transmission bandwidth requirements between different sites. Therefore, ROADM BU can provide customers with bandwidth-level routing scheduling capabilities, reduce the difficulty of bandwidth allocation planning when the submarine cable system is initially built, and improve the utilization of network bandwidth and reduce operation and maintenance costs. In addition, the ROADM BU provides the system disaster recovery capability. When a cable or underwater device is faulty, the ROADM BU bandwidth can be scheduled to fill the loss of signal power on the faulty side and isolate the faulty submarine cable section. In this way, the services of the stations that are not in the fault segment can communicate with each other. WSS ROADM BU (hereinafter referred to as WSS ROADM), however, provides wavelength-level bandwidth reconstruction. Based on the WSS technology, the 0%~100% insertion ratio can be achieved, which provides flexibility for network bandwidth planning and bandwidth requirement changes. Based on the preceding features, with the maturity of the submarine cable WSS technology, the WSS ROADM networking has obvious advantages and is increasingly favored by the market. Therefore, WSS ROADM is becoming an indispensable part of the submarine cable system.

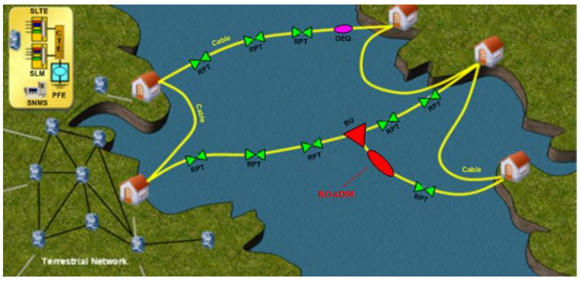

Figure 1: Application of the ROADM in the submarine cable system

In a submarine cable system using WSS ROADM, when an abnormal loss occurs in a submarine cable link that enters the WSS ROADM (for example, cable maintenance increases insertion loss or Repeater pump failure causes output optical power to plummet), the output spectrum of the WSS ROADM will no longer be balanced, causing system performance degradation. After passing through the next repeaters, the service wavelength power of the submarine cable link without failure, the non-linear effect is increased, and the power difference of the entire spectrum is increased. Using the active gain shape equalization function of WSS ROADM, the spectral spectrum can be effectively adjusted to significantly improve the performance.

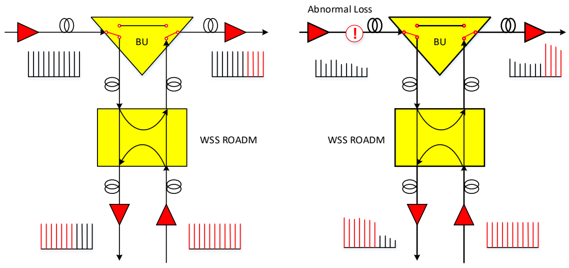

Figure 2: An abnormal loss occurs in a branch of the WSS ROADM

Especially in a submarine cable system with multiple WSS ROADM branches, for example, the submarine cable system shown in FIG.3, six stations communicate with each other. When the WSS ROADM trunk at station B is abnormal, the transmission services at other stations are affected. In this case, you only need to use the WSS ROADM gain spectrum adjustment function of the link. If the WSS ROADM does not support the dynamic gain spectrum equalization function, spectrum equalization needs to be performed on the stations involved in each affected service (for example, A, C, D, E, F in FIG.3), this operation is complex and difficult to maintain.

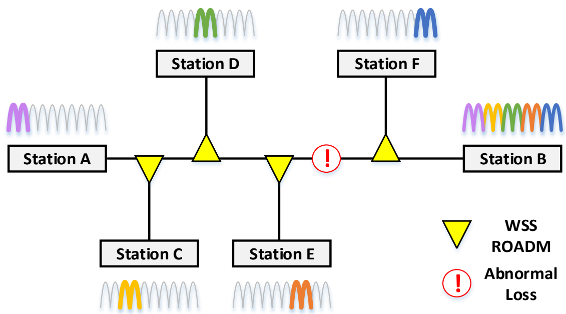

Figure 3: An abnormal loss occurs in in a submarine cable system with multiple WSS ROADM

In summary, by using the gain spectrum amplification function of the WSS ROADM, the spectrum type can be effectively adjusted, thus improving the service performance and reducing the maintenance cost of abnormal loss. This function also enables the WSS ROADM to have the functions of SEQ(shape equalizers) and

TEQ(tilt equalizers), which is crucial to long-fiber links.

This paper will experimentally study the impact of abnormal loss scenarios, such as cable maintenance and repeater pump failure on the performance of submarine cable systems using WSS ROADM. We will show that the performance degradation of the submarine cable system can be recovered and maintained using WSS ROADM's active gain shape equalization function.

2. EXPERIMENTAL SETUP

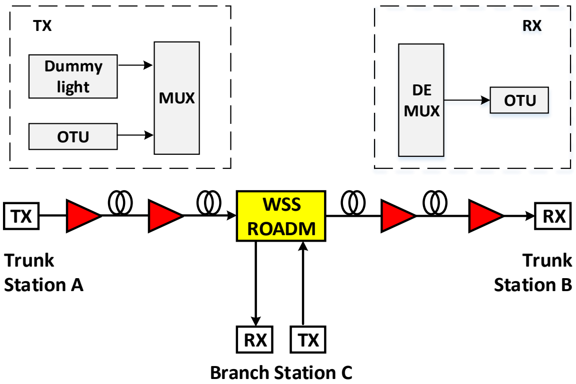

Figure 4: The WSS ROADM transmission system with a typical 3 stations

We build a WSS ROADM submarine cable system with a typical 3 stations for experimental verification, as shown in Figure 4. In the experimental system, the total length of the fiber link between station A and B is 5181 km, and one WSS ROADM is located between the links. The fiber between station A and the WSS ROADM is 1631 km long, and the fiber between station B and the WSS ROADM is 3550 km long. The station C is directly connected to the WSS ROADM. The 37.5 GHz spacing is used in the system, and a total of 128 channel of the C-band and extended C-band are used. Each of the station A and C has an OTU (Optical Transponder Unit) with a wavelength of 100G DQPSK, and the wavelengths are respectively 196.01875 THz and 191.33125 THz. ASE is used as the dummy light for the rest of the channels. The WSS ROADM is set to transmit 100 waves from station A to B, and 28 waves from station C to B.

3. REPEATER PUMP FAILURE

In a many repeaters cascaded submarine cable systems, the repeater will operate in a gain compression state. The pump failure of an repeater will cause its output optical power to drop, but after the next stage or multi-stage repeater amplification, the optical power will return to its original state[2]. If the pumping of the repeater in the previous stage of the WSS ROADM fails, due to the function of the multiplexing and demultiplexing of the services of the trunk and branch of the WSS ROADM, the channel with the reduced power is combined with the channel no power drop, which destroys the previous spectral equilibrium state. When it is transmitted to the next repeater, the original equilibrium state cannot be restored.

We performed a pump failure test on the repeater of the front stage of the WSS ROADM trunk side in the experimental system networking. The repeater uses four pump-shared architectures. When its pump fails, not only does the output optical power drop, but its output spectrum slope also changes, as shown in Figure 5.

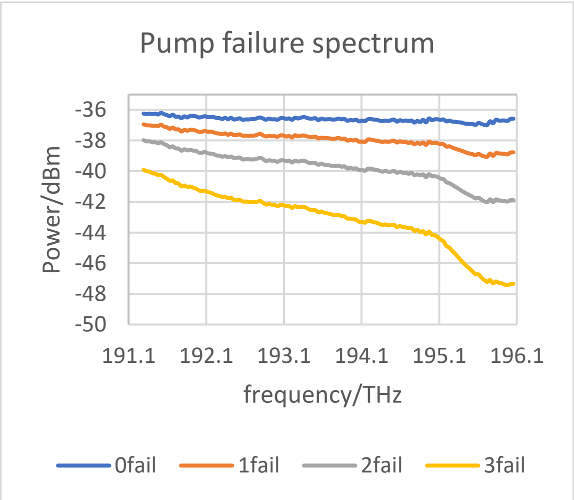

Figure 5: The output power spectrum of repeater when pump failures occur

After the transmitted light passes through the WSS ROADM, the channel with the reduced power of the trunk and the channel with the non-reduced power of the branch are combined, and the optical power of all the channels after the WSS ROADM is changed by the amplification of the subsequent PRT. According to the received spectrum of the B station, compared with the state when the repeater pump is not failed, the optical power transmitted by the branch increases, the optical power transmitted by the trunk decreases, and the spectrum also changes, as shown in FIG. 6. The received OSNR will also change significantly, as shown in Figure 7.

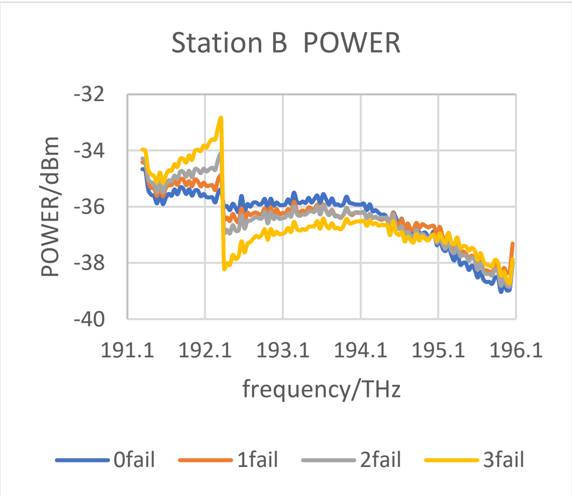

Figure 6: The received power spectrum of the B station when pump failures occur in the repeater

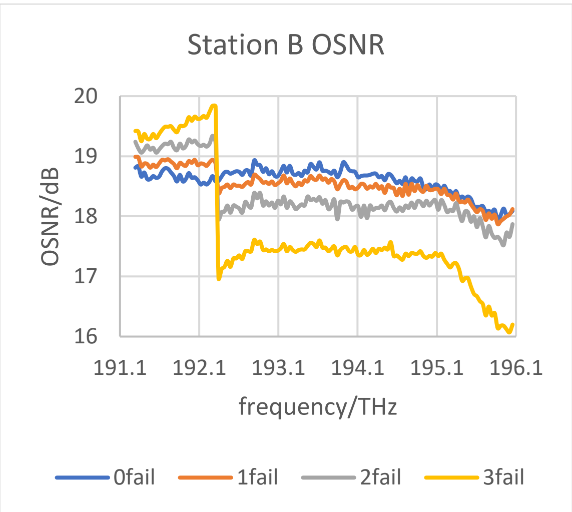

Figure 7: The received OSNR of the B station when pump failures occur in the repeater

As shown in Figures 8 and 9, we can significantly improve the performance degradation caused by repeater pump failure by using the active gain shape equalization function of WSS ROADM, so that the power and OSNR can be basically restored to the state when the repeater pump is not failed.

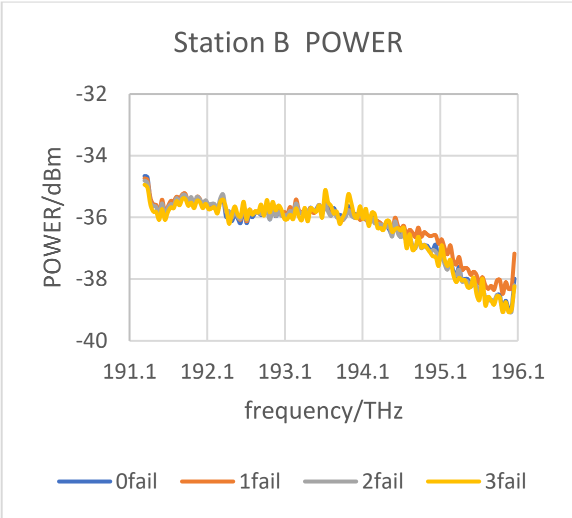

Figure 8: The received power spectrum of the B station after using the WSS ROADM's active gain shape equalization function when pump failures occur in the repeater

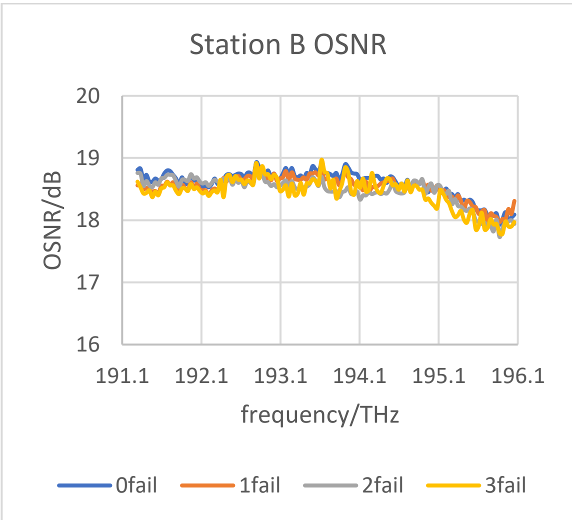

Figure 9: The received OSNR of the B station after using the WSS ROADM's

active gain shape equalization function when pump failures occur in the repeater

From Table 1, we can see that the BER of the OTU transmitted from the branch is worse although its OSNR is increased. This is because the optical power of the OTU increases, resulting in an increase in nonlinear effects, and the degradation caused by the nonlinear effect is greater than the optimization caused by the increase in OSNR, so the BER of the OTU transmitted from the branch is deteriorated.

The BER of the OTU transmitted from the trunk decreases as the OSNR decreases. By using the WSS ROADM's active gain shape equalization function, the power and OSNR received by station B are restored to the state when the repeater pump is not failed, and the BER is basically restored.

Scenario	pump fail number	191.33125 THz BER （Branch）	196.01875 THz BER （Trunk）
Before WSS ROADM equalization	0	1.93E-03	2.35E-03
	1	2.02E-03	2.15E-03
	2	2.03E-03	2.51E-03
	3	2.19E-03	5.18E-03
After WSS ROADM equalization	1	1.85E-03	2.32E-03
	2	1.97E-03	2.67E-03
	3	1.97E-03	2.62E-03

Table 1: The received BER of the B station before and after using the WSS ROADM's active gain shape equalization function when pump failures occur in the repeater

According to the above experimental data analysis, it can be seen that in the submarine cable system using WSS ROADM, the PRT pump failure of the WSS ROADM pre-stage will not only reduce the OUT optical power of the link, deteriorate its BER， but also affect the transmission performance of another chain. The output power of another chain will increase, causing the nonlinear effect to increase. By using the WSS ROADM's active gain spectrum equalization function, the impact of PRT pump failure in the WSS ROADM pre-stage can be effectively improved and basically restored to its original state.

4. BROKEN FIBER REPAIR

In the actual submarine cable system, the cable is sometimes destroyed due to human maritime activities or natural activities. At this time, the cable is required to be repaired. After the repair, the span needs to add a cable of about 2.5 times the water depth. For the 8000m sea area, it is equivalent to adding about 3dB insertion loss in the span. If the submarine cable maintenance is located in the adjacent span of the WSS ROADM, Since the WSS ROADM adds and drops the channels of the branch and the trunk, the channel with reduced power is combined with the channel whose power is not degraded, and the spectral equilibrium state is destroyed.

As shown in Figures 10 and 11, after adding 3dB insertion loss to the previous stage of the WSS ROADM trunk, similar to the repeater pump failure phenomenon, the received power and OSNR in the full spectrum of the station B change significantly. At this point, the active gain spectrum equalization function of the WSS ROADM can be used to restore the spectrum and OSNR to the state before the submarine cable is repaired.

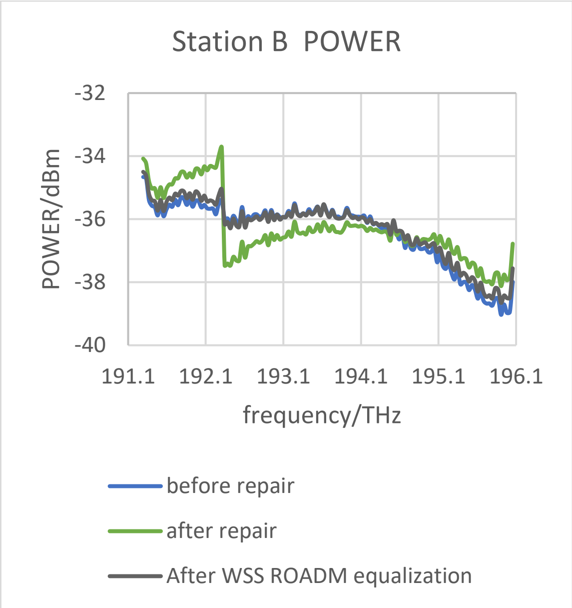

Figure 10: The received power spectrum of the B station before and after using the WSS ROADM's active gain shape equalization function after a submarine cable maintenance

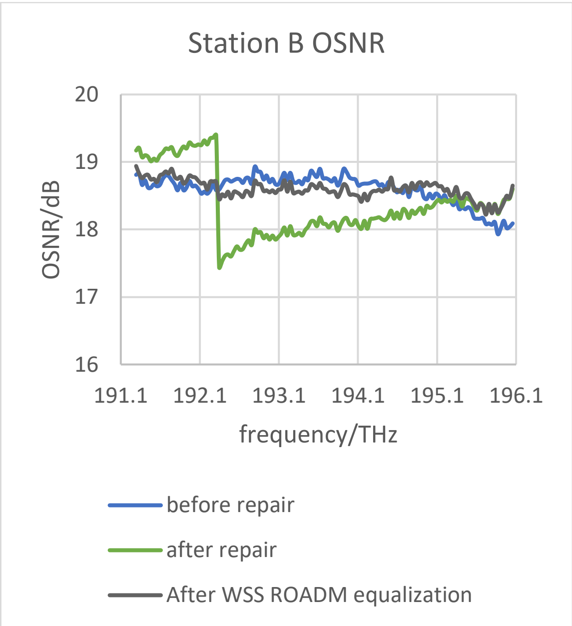

Figure 11: The received OSNR of the B station before and after using the WSS ROADM's active gain shape equalization function after a submarine cable maintenance

Scenario	191.33125 THz BER （Branch）	196.01875 THz BER （Trunk）
Before repair	1.93E-03	2.35E-03
After repair	2.08E-03	2.12E-03
After WSS ROADM equalization	1.94E-03	2.14E-03

Table 2: The received BER of the B station before and after using the WSS ROADM's active gain shape equalization function after a submarine cable maintenance

As shown in the Table 2, the submarine cable maintenance is similar to the Repeater pump failure scenario. Although the OSNR of the branch service wave increases, the BER of the branch service wave is worse. However, the OSNR of the service wave of the trunk increases slightly, and the BER performance is optimized. After using the WSS ROADM active gain shape equalization function, the OSNR is still slightly optimized.

According to the above experimental data analysis, it can be seen that in the submarine cable system using WSS ROADM, the submarine cable maintenance is similar to the repeater pump failure scenario. By using the WSS ROADM's active gain spectrum equalization function, the impact of cable repair can be effectively improved and restored to its original state.

5. CONCLUSION

The active gain shape equalization function of the WSS ROADM can effectively balance the spectrum and improve the traffic performance. Therefore, the impact of the abnormal loss on the traffic performance of the submarine cable system can be reduced. Especially for the complex submarine cable system, the time and the cost of repairing the abnormal loss can be greatly reduced. Therefore, the active gain shape equalization function of the WSS ROADM is very important for the submarine cable system.

6. REFERENCES

[1] Chesnoy, José, ed. Undersea fiber communication systems. Academic press, 2015.

[2] Changwu Xu, A MORE RELIABLE PUMPS REDUNDANCY DESIGN. SubOptic 2016.

