DEMOSTRATION OF EFFECTIVE IDLER SOLUTIONS IN SUBSEA FIELD TRIALS

Xiaohui Yang, Emily Burmeister, Hai Xu, Pierre Mertz, Steve Grubb, Dave Welch
Email: xiyang@infinera.com

Infinera Corporation, 169 Java Drive, Sunnyvale, CA 94089 USA

Abstract: Two types of idler solutions, using single-polarization CW lasers and filtered ASE noise, have been experimentally compared across two subsea routes with multiple advanced modulation formats. The performance benefit of the idlers with regard to relative power and channel plan, as well as polarization related system stability is reported. The results show that the CW idler solution provides potential best performance and the ASE-based idler solution offers a great compromise between system performance improvement and cost effectiveness. Non-polarized idler solution, such as ASE based idler, can also help to limit polarization-related power fluctuation and largely benefit system stability and margin.

1. INTRODUCTION

As signal processing-based coherent phase modulation technologies mature, an increasing number of legacy submarine systems are being upgraded to advanced modulation formats to take advantage of the higher spectral efficiency. Generally, DSP based coherent modulations can compensate most linear effects and their performance is largely limited by nonlinearities and noise. This makes signal power optimization a critical part in system design rules. In addition, nonlinearities are more dominant on legacy submarine cables which often have smaller effective fiber core, high output power repeaters and periodic dispersion maps. In order to reduce the power per channel and thus nonlinear penalty, it is often critical to implement an idler solution since subsea repeaters run in constant power mode and repeater output power can only be adjusted in a very limited range. Moreover, channel count on a subsea cable can vary from just a few to full-loading through the upgrade phases and the power per channel should be kept constant and the repeater should be properly loaded for stability and performance to insure a seamless capacity upgrade.

In legacy submarine systems high power single polarization CW laser based idlers have been widely utilized. There are several issues with these idlers: (1) small power variation of idlers may create large performance change due to sparse loading; (2) High power idler can lead to strong spectral hole burning and cause sub-optimal in its near region [1-2]; (3) When polarization of all the single-polarized idlers are aligned, it might create strong cross-polarization effect and impact polarization-multiplexed coherent signal performance. Recently, idler development has moved to use an array of CW lights at relatively lower power per wavelength to address the first two issues. Polarization dependence can be reduced by applying either polarization multiplexing or polarization scrambling. More cost-effectively, filtered ASE noise can be used as idlers to address some of above issues. The trade-off of using low cost filtered ASE noise as idlers is that ASE noise contains amplitude fluctuations which may cause phase noise on nearby signal channels and lead to performance degradation [3-4]. In this paper, two types of idler solutions, single-polarization CW lasers and filtered ASE, have been experimentally compared across 2 subsea routes ranging in length from 3,000 - 6,000 km with multiple advanced modulation formats. The performance benefit of the idlers with regard to relative power and channel plan, as well as polarization related system stability is reported.

2. EXPERIMENTS AND RESULTS

The first route (Route-A) is a 5700km 82-span link with average 14.3dB span loss and comprised of NZDSF with in-line periodic compensation. The testing diagram of Route-A is shown in the figure 1. At the transmitter, a tunable laser (signal channel) and 80-channel DFB laser source spanning from 191.725THz to 193.7THz at 25GHz spacing (aggressors) were modulated with 15.3Gbaud BPSK. Then they were combined and polarization multiplexed by splitting with a polarization maintaining splitter (PMS), delaying one arm, and recombining using polarization beam combiner (PBC). All the channels were then sent through an 8-way deinterleaver and interleaver pair, and connected with patchcords of varying lengths for decorrelation to create the 80-channel PM-BPSK source with best match client traffic conditions. Next, the spectrum was combined with the idlers and pre-emphasized by a Dynamic Spectral Equalizer (DSE) at the booster amplifier, and then launched into the subsea cable. At the receiver, the signal channel was optically filtered out before being sent into a coherent receiver. In order to characterize performance across the spectrum, the signal channel was tuned in wavelength, the corresponding aggressor laser at the signal channel wavelength was turned off, and measurements were repeated at each testing wavelength.

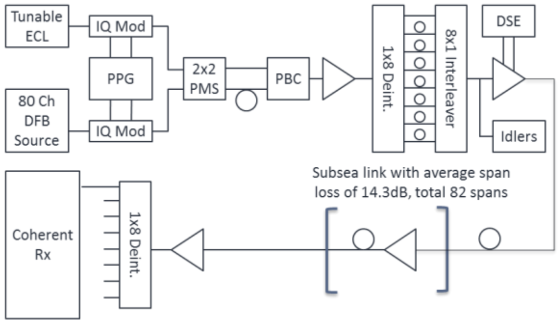


Figure 1: Route-A testing setup diagram

System performance was tested between frequencies 192.2THz and 193.6THz at every 200GHz due to limited repeater bandwidth. Three configurations were tested: (1) Full loading, or 80 PM-BPSK channels at 25GHz spacing; (2) Half loading with CW idler, or 40 PM-BPSK channels at 50GHz spacing interleaved with 40 CW idler channels at 25GHz grid; and (3) Half loading with the ASE idler, which replaces the CW idlers in the "Half loading with CW idler" case. In configuration (2) and (3), a global power offset between signal channels and idlers was applied for optimal performance. The Q values in the three configurations are shown in figure 2. Due to high nonlinearities from neighbouring aggressors, the full loading case had worse Q across the spectrum, and half loading with CW idler without any offset gave the best performance among the three. In half loading with the ASE idler configuration, the power of the ASE idlers needed to be lowered by 4dB for optimal Q values. This gave a balance among cross-phase modulation (XPM) introduced from ASE idler, signal channel OSNR and nonlinearities from all modulated channels.

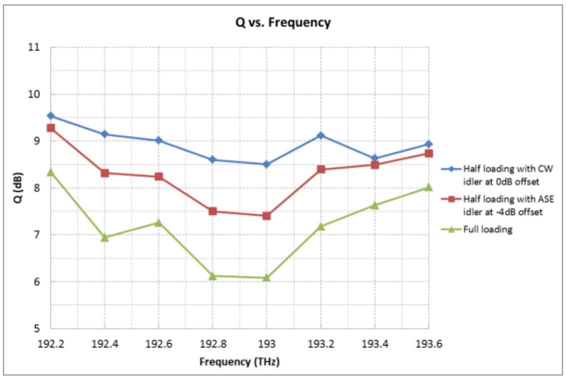
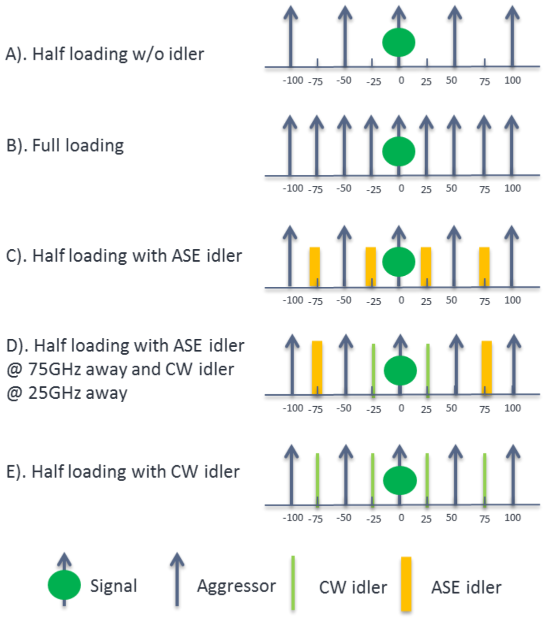
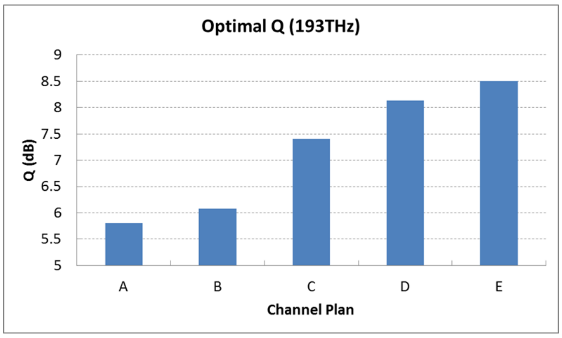


Figure 2: Route-A system performance with different channel plans

In figure 2, it is worth noticing that there exists a larger Q difference near the middle of the testing spectrum than at the edges. It is mainly because of the zero dispersion wavelength of the periodical dispersion map near the middle of the testing spectrum (around 193THz) in the Route-A which results in higher nonlinear penalty. During the two half loading cases, extra cross-phase penalty was expected after switching from the CW idlers to the ASE idlers. At the edge of the testing spectrum, where the system was more linear, Q could be almost recovered by dropping the ASE idler power, which led to an increase of signal power as well as signal OSNR due to the constant power operation of the repeaters. However, in the middle of the spectrum where the system was highly nonlinear, although Q was improved by dropping ASE idler power (to -4dB offset), the optimized Q was not able to reach the same performance achieved with the CW idlers.



(a). Channel plan illustrations



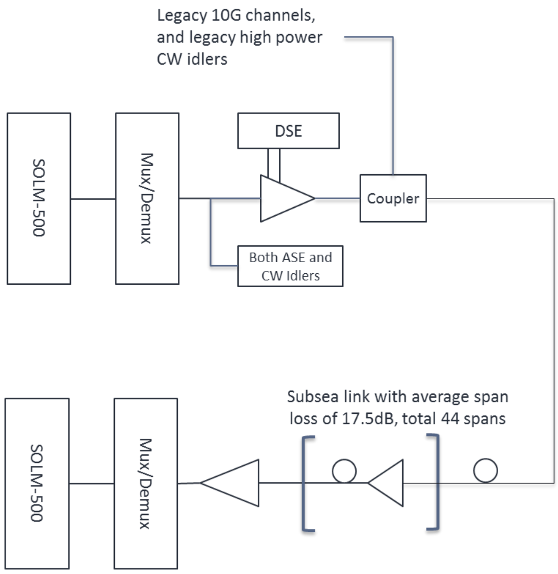
(b). Comparison of optimal Q across the tested channel plans

Figure 3: Performance comparison for different channel plans on Route-A

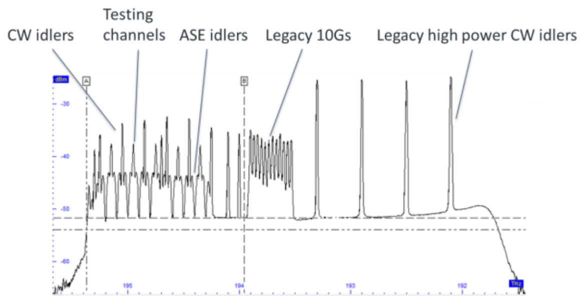
Further comparison of idler impact was conducted with five channel plans in the high-nonlinear region. The five channel plans within +/-100GHz from the signal channel are illustrated in the figure 3(a) and they were evenly applied across the whole testing spectrum during each test. Channel plan A was loaded with 50GHz spaced aggressors without any idler; channel plan B was full loading with aggressors spaced by 25 GHz; channel plan C was half loading with interleaved ASE idlers; channel plan D was a mixed idler solution with ASE idlers interleaved 75GHz away from signal and CW idlers at

25GHz away; and channel plan E was half loading with interleaved CW idlers. Optimal performance at 193THz in each channel plan was measured and the results are shown in figure 3(b). The optimal Q from the experimental data without any idler was only 5.8dB for 50GHz spacing using channel plan A and 6.1dB for 25GHz spacing using channel plan B. Through switching half of the aggressors to ASE idlers from channel plan B to C, the optimal Q was improved to 7.4dB with 4dB power per channel offset between the signal and idlers. Upon replacement of two 25GHz neighbouring ASE idlers with CW idlers to reduce XPM (channel plan D), the optimal Q could be further improved to 8.1dB without any power offset between the ASE idlers and the signal. The best Q of 8.5dB was observed with purely CW idlers and no offset from the signal power level (channel plan E).The above results indicate that idlers helped the system performance in route-A with the CW idlers providing the best solution for static optimal Q. It was found that ASE idlers can be most effective with moderate spectral spacing and reduced power level relative to signal channels.

The second route (Route-B) is a 3400km 44-span compensated link with LEAF and RS fibers. Tests were conducted using Infinera photonic integrated circuit (PIC) based SOLM-500 modules and both CW idlers and ASE idlers, along with existing 10G traffic and legacy high power CW idlers. In the test the SOLM-500 ran with Infinera proprietary enhance BPSK format (eBPSK) at 14.25Gbaud, which is based on Trellis Coded Modulated (TCM)-QPSK[5], for best performance in the route. The testing setup diagram is shown in figure 4(a). At transmitter, six eBPSK channels at 200GHz spacing were combined with ten CW idlers and a filtered ASE idler in the red part of the transmission window. Then they were amplified and pre-emphasized by DSE and coupled with legacy spectrum, which included twelve legacy 10G channels and four high power CW idlers in the blue part of transmission window, before sent into subsea link. At receiving side, the testing channels were first filtered with a deinterleaver, and then sent into another SOLM-500 module for Q measurements. The channel plan under testing is illustrated by receive spectrum shown in the figure 4(b).



(a). Route-B testing setup diagram



(b). Route-B receive spectrum

Figure 4: Route-B testing system

Long term stability, as a crucial part in system margin, is affected by many factors such as SLTE power fluctuations and polarization drifting through the entire system etc. Time Varying System Performance (TVSP) has been widely accepted to quantify system margin with long term stability. On route-B, the testing system was optimized for TVSP of all six eBPSK channels in order to evaluate system margin. To calculate margin the performance was measured over an extended period on all test channels to determine the average Q and standard deviation of performance over time. The margin of each channel is defined as,

Qave – 5 * Qsigma – Qlimit,

where Qave and Qsigma are the average Q and standard deviation of Qs from the stability duration, respectively, and Qlimit is the system commissioning limit. The stability durations were one day each in two configurations: a mixed configuration where both ASE idler and CW idlers were used, spectrum as shown in figure 4(b), and a configuration with only CW idlers. The average Qs and the margins of all 6 eBPSK channels with both configurations, as well as margin improvement between the two configurations, are listed in the table 1.

Frequency (THz)	Average Q with CW idler only (dB)	Margin with CW idler only (dB)	Average Q with mixed CW and ASE idlers (dB)	Margin with mixed CW and ASE idlers (dB)	Margin improvement with ASE Idlers (dB)
194.35	12.58	0.46	12.14	1.19	0.73
194.55	13.04	0.65	12.49	1.60	0.95
194.75	13.13	0.75	12.57	1.69	0.94
194.95	13.64	1.11	13.05	2.19	1.09
195.15	13.79	1.33	13.19	2.33	1.01
195.35	13.17	-0.23	12.18	1.21	1.44

Table 1: Route-B margin comparison

From the results, we found that average Q values in the case with only CW idlers were generally more than 0.5dB better than the case in which ASE idlers were present. This is due to the nonlinear noise-signal interaction penalty induced by the ASE idler on the testing channels. However, with respect to the system margin, the configuration with only CW idlers is about 1dB worse than the mixed CW and ASE idlers case, and one channel fell below commissioning limit over the course of the stability test. The key behind the optimal margin is performance fluctuations (Qsigma), and larger Q fluctuations were observed in the CW idler only configuration. Due to sparse channel loading of eBPSK in the route-B when there were no ASE idlers, the majority of the light sources were single-polarization. Though the additional 10 low-power CW idlers to the legacy spectrum improved the randomicity of signal polarization in the system, the system was still largely polarization dependent, in comparison to the system with mixed ASE and CW idlers. The high polarization dependence of system could be easily translated into large system performance fluctuation through polarization related effects, such as polarization hole burning and polarization dependent gain etc., while the state of polarization of these single-polarization signals migrated along the subsea link. ASE idlers can effectively lower these polarization related system impacts and reduce Q fluctuations. On route-B, the penalty from the ASE idlers from nonlinearities was offset by the gain from long term stability, and the inclusion of ASE idlers improved overall system margin.

3. CONCLUSIONS

Both CW idlers and ASE idlers have been experimentally compared in two subsea routes. The results show that the CW idler solution provides the least penalty to the active channels for potential best performance, meanwhile the ASE-based idler solution, in spite of introducing XPM, offers a great compromise between system performance improvement and cost effectiveness, especially when combined with CW idlers. Comparable performance to CW idler solution can be achieved when ASE idlers are positioned at moderate spectral spacing from signal channels or operate in less nonlinear regions. In addition, non-polarized idler solutions,

Copyright © SubOptic2013

such as ASE based idlers, can also help to limit polarization-related power fluctuation and benefit the system stability and margin.

REFERENCES

[1] Hidenori T. et al, Impact of polarization hole burning effect in transoceanic wavelength division multiplexed systems, Proc. OFC’89, WE6-1 (1989)

[2] A.N.Pilipetskii et al., Spectral hole-burning in long-haul WDM transmission, Proc. OFC’04, FM3(2004)

[3] Alberto B. et al., Modeling of Signal-Noise Interactions in Nonlinear Fiber Transmission with Different Modulation Formats, Proc. ECOC’09, P10.4.6. (2009)

[4] Xiaogang L. et al., Impact of nonlinear signal-noise interactions on symbol-aligned and -interleaved formats in dispersion managed coherent PM-QPSK systems, Optical Express, vol. 20, pp19183-17191, July 2012

[5] Pierre M. et al., TCM-QPSK Performance in Subsea Trials, Proc. ECOC’12, P4.10. (2012)

Copyright © SubOptic2013