Impact of Frequency Separation between Orthogonal Idlers on System Performance

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Abstract: Continuous-wave (CW) idlers are widely used in submarine links to control channel power to optimize transmission performance. The use of two orthogonally polarized CW lasers as a single idler, instead of a single free-running laser source, has been proved to reduce polarization dependence fluctuation in channels close to it. The frequency difference between the two CW lasers must be carefully controlled, otherwise the system may suffer significant penalty.

1. Introduction

Power control and idler placement is critical for optimizing transmission performance in submarine links. Legacy cables were designed with high output power repeaters and dispersion management for on-off-keying (OOK) modulation formats, which tolerates more nonlinearity than coherent phase modulated counterparts. In recent years, coherent advanced modulation formats, such as binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and quadrature amplitude modulation (QAM), dominate in submarine links [1-2]. These formats employ digital signal processing (DSP) algorithms to compensate most linear distortions of the waveform and are generally limited by nonlinear effects and noise in the link. Therefore they require much lower per-channel launch power, which is especially true for channels close to the zero dispersion wavelength (ZDW), where cross-phase-modulation (XPM) penalty from neighbouring channels becomes much more detrimental.

Single-polarization (SP) and dual-polarization (DP) continuous-wave (CW) idler have been effective components in submarine links to control channel power in both the entire passband and within a narrow bandwidth of several hundred Giga-Hertz [3-4]. SP CW idler, as a single free-run laser, is simple and of low cost, but can cause polarization dependent penalty to channels close to it. A DP CW laser, on the other hand, utilizes two orthogonally polarized lasers as a single idler. These two lasers, whose total power can be the same as that of a SP idler, have much less polarization dependent penalty while maintain the same level of power control over channel power.

In a DP CW idler, the frequency of the two orthogonally polarized lasers must be slightly tuned away from each other. During submarine lab test, field trials, and simulation, we found out that when the frequency separation between the two lasers is within a certain range, neighboring channels will experience Q penalty and fluctuation due to beating of the two lasers.

In this paper, we investigate the impact of laser frequency separation between the two lasers in a DP CW idler, both by experiments in a field trial and in a lab recirculating loop. We will also demonstrate the effect with simulation results.

2. Experimental Results

In this section, we present test results in a field trial over a trans-pacific submarine link, and lab test results in a recirculating loop. The modulation formats used in these tests include BPSK, QPSK, and 8QAM.

2.1 Field Trial Test

The link used for field trial is 8870 km in length, with 207 spans at an average span loss of 11.3 dB. The link is comprised of NZDSF with periodical in-line compensation. The ZDW of the cable is at about 193.4 THz.

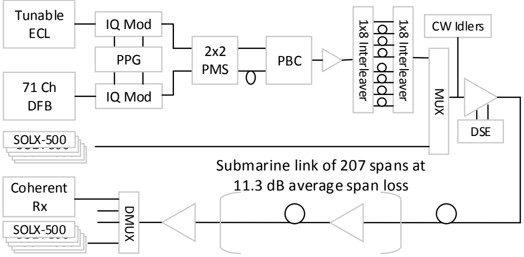


Fig. 1. Field trial test setup

The test setup is as shown in Fig. 1. The Tx consists of a total of 122 channels at 25 GHz channel spacing from 191.80 THz to 195.05 THz, within which a bandwidth of 200 GHz from 193.725 to 193.925 THz are reserved for guard band. Among the channels there are 50 channels from five line modules of Infinera's SOLX-500, 71 loading channels generated by DFB lasers, and an ECL tunable laser for test channel. All channels are modulated with 15.3 GBaud BPSK format. The test channel and loading channels are modulated in two separate IQ modulators, then combined and polarization multiplexed with a 2x2 polarization maintaining splitter (PMS), an optical delay in one arm, and then combined again in a polarization beam combiner (PBC). The recombined channels are decorrelated through a pair of 1x8 interleaver/deinterleaver and seven patchcords of different lengths between them. After decorrelation these channels are combined with 50 channels from five SOLX-500 line modules, and two DP CW idlers at 191.7 THz and 193.85 THz, respectively. Finally all channels are pre-emphasize in a dynamic spectrum equalizer (DSE) and amplifier before being launched into the submarine cable. The launch spectrum, after pre-emphasis, is shown in Fig. 2. In this test, the CW idler at 193.85 THz is close to ZDW.

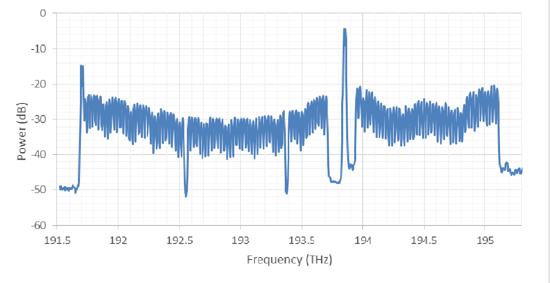


Fig. 2. Field trial launch spectrum

At the Rx side, a demultiplexer (DMUX) sends the test channel to a coherent receiver, which utilizes a Tektronix DPO71604B sampling scope and off-line processing. At the same time, another set of five SOLX-500 line modules provides real-time Q values of the 50 channels from the Tx SOLX-500s.

In normal tests, the two orthogonally polarized lasers in each CW idler are kept at +/- 6 GHz away from the idler's nominal frequency of 191.7 THz and 193.85 THz, respectively. To investigate the impact of the laser frequency separation, the separation in idler 193.85 THz is gradually reduced down to +/-1 GHz at a step size of 1 GHz, and then further reduced to +/- 0.5 GHz, +/- 0.2 GHz, and +/- 0.1 GHz. At each separation, Q values of all 50 SOLX channels are measured and recorded. The test channel are also checked at the rest of the bandwidth. Fig. 3 shows the monitored deltaQ values of the 50 channels during the process.

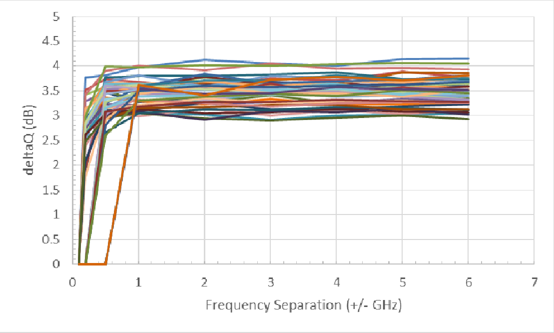


Fig. 3. Field trial test results

In the results, points at deltaQ = 0 dB means they are below forward error correction (FEC) limit and the channel fails. It is clear that at +/- 0.1 GHz separation, all 50 channels have failed. As the two lasers separate farther in frequency, channels far away from the CW idler start to recover, while those close to the CW idler still experience Q loss or Q penalty until the separation becomes about +/-1 GHz. After that channel Q values become stable and independent to frequency separation.

2.2. Recirculating Loop Test

The recirculating loop contains a total of 8 spans. The first 6 spans each has about 50 km of fiber, of which the two halves are two different types of negative-dispersion fiber. The seventh span is 50 km NDSF fiber to compensate dispersion. The last span contains 10 km of LS fiber and loop supporting equipment, including a loop synchronous polarization scrambler (LSPS), a DSE, an acoustic optical switch (AOSW), and a 3 dB coupler [5-6]. The 10 km LS fiber plus the supporting equipment is equivalent to 60 km of fiber. The ZDW of the loop is around 193.1 THz.

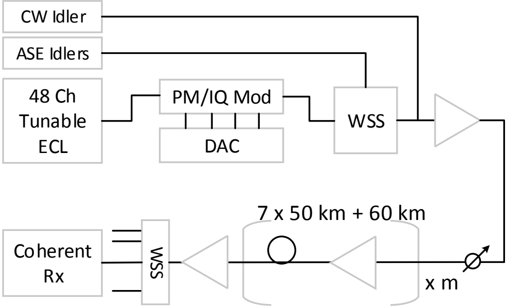


Fig. 4. Recirculating loop test setup

The test setup of the loop experiments is shown in Fig. 4. The Tx is comprised of three groups of signals. The first are 48 test channels from ECL, which can be tuned within the entire C band, are modulated in a PM/IQ modulator. Second, an amplified spontaneous emission (ASE) light source fills in the rest of the spectrum as loading channels. These two groups of signals are combined in a wavelength selective switch (WSS) that also pre-emphasizes the launch spectrum. Finally, a dual-polarization CW idler combines with the test channels and ASE idler. These signals are amplified and launched into the recirculating loop.

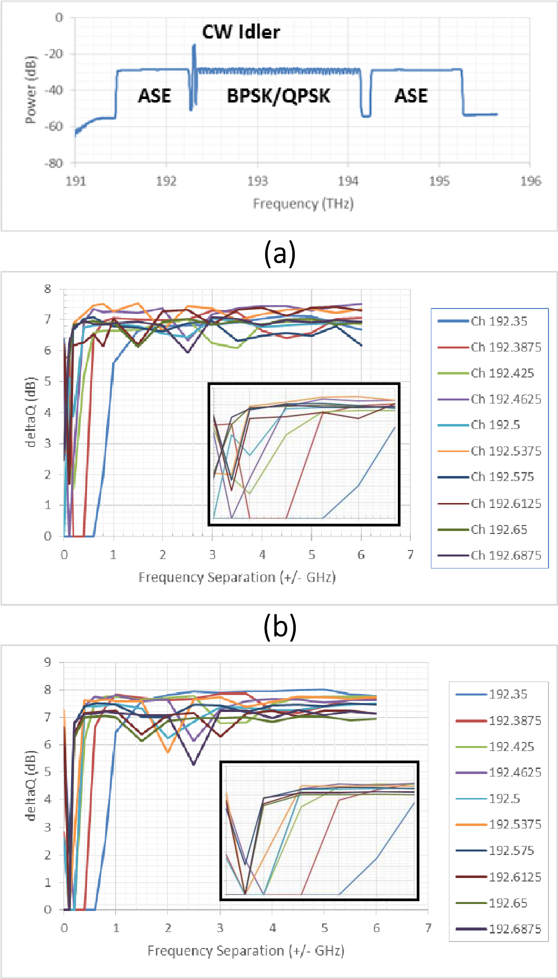
At Rx side, a WSS drops test channels to a coherent receiver, which utilizes a Tektronix DPO72304DX, triggered by loop clock, and off-line processing.

Three modulation formats, i.e., BPSK, QPSK, and 8QAM, are tested in the recirculating loop. Table 1 shows the parameters of these formats used in the test.

	BPSK	QPSK	8QAM
Baud Rate (Gbaud)	31.5	31.5	21
Ch. Spacing (GHz)	37.5	37.5	25
CW Idler Freq. (THz)	192.3	192.3	192.45
Ch next to Idler (THz)	192.35	192.35	192.5
Ch. Count	48	48	48
Loop Round Trips	18	10	3
Transmission Distance (km)	7380	4100	1230

Table. 1. Parameters of modulation formats.

In the tests, frequency separation between the two lasers of the DP CW idler start from 0, then increases gradually at 0.1 GHz step size to +/- 1 GHz. After that, the step size adjusts to 0.5 GHz for the rest of the tests all the way to +/-6 GHz separation. Channel Q values are monitored during the process.



(a)

(b)

(c)

Fig. 5. Loop test results of BPSK and QPSK.

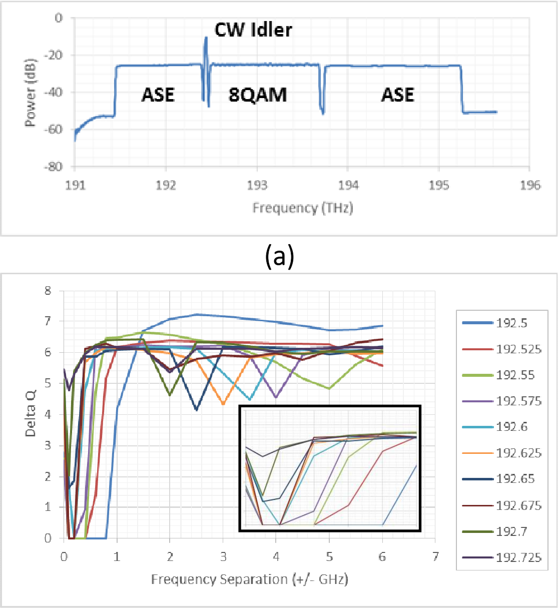
(a) Launch signal spectrum.

(b) BPSK test results.

(c) QPSK test results.

For BPSK and QPSK, the transmission distance is 7380 km and 4100 km, respectively. The launch signal spectrum and deltaQ vs. Frequency Separation is shown in Fig. 5. The inset in the lower-right part of the deltaQ results is an enlarged copy of the results from 0 to +/- 1 GHz separation

For 8QAM format, the launch signal spectrum and deltaQ vs. Frequency Separation is shown in Fig. 6.



(a)

(b)

Fig. 6. Loop test results of 8QAM.

(a) Launch signal spectrum.

(b) 8QAM test results.

With all three formats, the impact of frequency separation on channel Q performance is similar to what has been observed in the field trial. One major difference, as shown in the inset of Fig. 5 (b) and (c) as well as in Fig. 6(b), is that at zero separation, some channels in the loop test results have a significant deltaQ at the beginning, but as the separation increases deltaQ reduces to zero or near zero and then back to normal. This is due to the fact that the real frequency of the two orthogonally polarized laser are slight off their nominal values and they drift slightly from time to time by a few tens to a hundred mega Hertz. A second difference is that the measured Q values fluctuate in channels with the separation from about +/- 2 GHz to +/- 4 GHz. This will be further investigated in the future.

3. Simulation Results

We simulate the performance of BPSK channels separated by 50GHz channel separation in a typical subsea link of 7000km length. The idlers are inserted at 192.325THz and the channels span 192.THz to 193.2THz.

The results are show in Fig. 7. Similar to the lab experiments, the idlers have appreciable penalty for any separation below 1GHz. At 500MHz separation penalty is severe for channels neighbour to the idlers. The effects gets stronger as the separation decreases. At 10MHz, channels as far as 1THz from the idlers are completely blocked by the noise from the idlers.

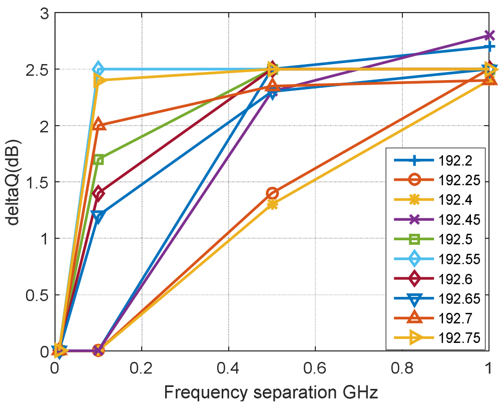


Fig. 7. Simulation results of BPSK over 7000 km of subsea link.

4. Summary

Submarine field trial, lab tests, and simulation results demonstrate the risk of catastrophic traffic failure when the two lasers in a DP CW idler are within a range of about +/- 1 GHz. The findings are of importance for subsea cable systems which require the use of CW idlers to control power per channel and optimally load the wet plant. Orthogonally polarized CW idler is a field proven component to reduce polarization dependent performance fluctuation in submarine links. In order for the system operator to have the desirable advantages of dual-polarization idlers, however, the designing and controlling of the frequency separation between the two idlers has to be done with great care, otherwise the system can suffer from great penalties.

5. REFERENCES

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