Experimental 20 Gbit/s Absolute Polar Duty Cycle Division Multiplexing - Polarization Division Multiplexing (AP-DCDM-PolDM) Transmission

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***Abstract* - 20 Gbit/s (2 × 2 × 5 Gbit/s) Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM)-Polarization Division Multiplexing (PolDM) over 180 km standard single-mode fiber has been experimentally demonstrated in order to double the capacity of PolDM and increase the maximum dispersion uncompensated reach. The AP-DCDM-POLDM performance is examined utilizing a polarization stabilizer. By increasing the length from 0 km (back-to-back) to 180 km the 10 Gbit/s single AP-DCDM channel without SOP stabilizer experienced ~1 dB penalty as compared to around 2 dB penalty when the SOP stabilizer is active.**

Keywords- Optical Communication; Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM); PolDM.

I. INTRODUCTION

Absolute polar duty cycle division multiplexing (AP-DCDM) appears promising for its spectral width and its chromatic dispersion tolerance [1-3]. The small spectrum of AP-DCDM system reduces the inter channel coherent crosstalk in AP-DCDM-WDM systems. The possibility of setting channel spacing as narrow as 62.5 GHz (0.5 nm) for 40 Gbit/s AP-DCDM signals over WDM was confirmed [3]. As reported in [3], a capacity of 1.28 Tbit/s (32 x 40 Gbit/s) was packed into ~ 15.5 nm (1550-1565.5 nm) EDFA gain-band with 0.64 bit/s/Hz spectral efficiency by using 10 Gbit/s transmitter and receiver. Good dispersion tolerance makes AP-DCDM very attractive for uncompensated optical links [1-3].

Transmission capacity enhancement is a key issue for network for today's telecommunication. Polarization division multiplexing (PolDM) is well known technique for doubling the spectral efficiency [4].

In PolDM systems, two signals are transmitted at the same wavelength with orthogonal states of polarization (SOP).

At the receiving end, the polarization channels are demultiplexed at polarization beam splitter and detected independently. In PolDM applications, due to external distraction factors an automatic state of polarization stabilization is actually desirable. Because of coherent cross talk between the two orthogonally polarized channels, SOP stabilizers cause impairments in PolDM applications [8, 9].

We have already discussed the implementation issues and advantages of AP-DCDM over a single wavelength, Wave length division multiplexing (WDM) and PolDM based on the simulation results [1-3].

In this paper, for the first time to the best of our knowledge, the AP-DCDM system has been exploited experimentally together with PolDM using a SOP in order to transmit over 180 km at an aggregated bitrate of 20 Gbit/s (2 × 2 × 5 Gbit/s), without dispersion compensation.

The polarization stabilizer which is used in this experiment is described in [8]. Bit-Error Rate (BER) versus Optical Signal Noise Ratio for various standard single mode fiber lengths is measured in a case of AP-DCDM over PolDM system utilizing a SOP stabilizer. In a case of single AP-DCDM channel, the BER versus OSNR is measured for both with and without the SOP stabilizer.

The experimental study shows the capabilities of AP-DCDM format to double the capacity of PolDM in dispersion uncompensated condition and evaluates the effect of the SOP stabilizer on propagation penalties.

This paper is organized as follows. Section II describes the experimental setup for a 2-channel AP-DCDM system over PolDM. Section III shows the performance of AP-DCDM over PolDM System. Section IV concludes our paper.

II. EXPERIMENTAL SETUP

Figure 1 illustrates the experimental setup of AP-DCDM over PolDM. As shown in Figure 1a, the evaluation starts with two AP-DCDM channels (2 x 5 Gbit/s) with PRBS of 2^{31}-1 and followed by 2 PolDM channels (2 x 10 Gbit/s) (Figure 1b). In this setup, each PolDM channel contains two users that were already multiplexed by using AP-DCDM, which means each PolDM channel contains 2 x 5 Gbit/s that can offer a possible transmission rate of 20 Gbit/s (2 x 2 x 5 Gbit/s) for PolDM system. Channel 1 and Channel 2, each at 5 Gbit/s with PRBS 2^{31} -1 are carved with one electrical RZ pulse carvers at 50% of duty cycle and NRZ pulse carver, respectively. The voltages for both users at the multiplexer input are identical. Both users' data are multiplexed via AP-DCDM multiplexer [1-3]. Subsequently, the rectifier circuit (REC) is used to produce an absolute signal [1-3]. The signals are used to modulate a distributed feedback laser (DFB), which operates at 1548.51 nm wavelengths using a

Mach-Zehnder-Modulator (MZM). The modulated AP-DCDM signal is divided into 2 uncorrelated copes using a fiber spoil, which has a delay of about 20 µs. Power for 2 signals is identical, two signals orthogonally polarized using a fiber polarization controller (PC) and combined using a polarization beam combiner (PBC).

Using an electro absorption modulator (EAM) one of the signals is marked with a pilot tone at one Megahertz.

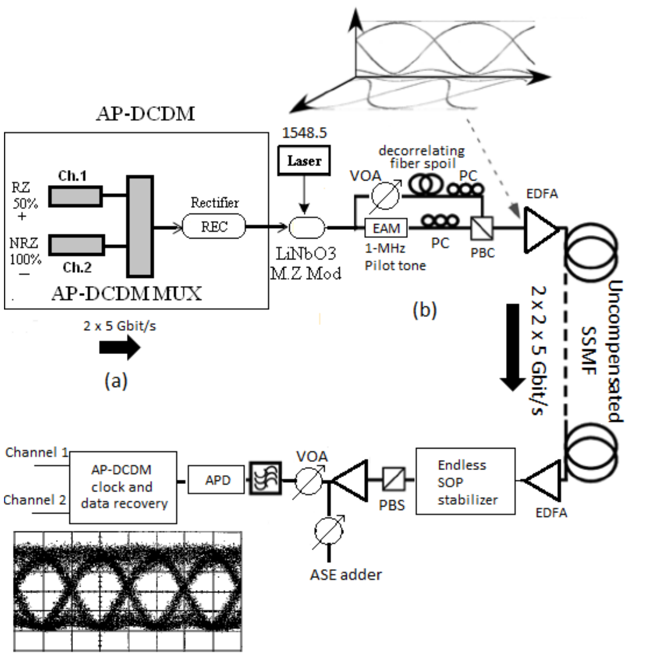

Figure 1. AP-DCDM-PolDM setup. (a) 2 x 5 Gbit/s AP-DCDM setup (b) 2 x 10 Gbit/s AP-DCDM signal over PolDM. The eye-diagram was taken for the 180 km link while transmitting both SOPs

A polarization multiplexed signal at an overall bit-rate of 20 Gbit/s is generated and launched in an uncompensated single mode fiber (SMF) link.

After transmitted over the fiber, by using a fiber polarization beam splitter, the 2 AP-DCDM- PolDM channels at the same wavelength are de-multiplexed.

In order to indemnify the random polarization fluctuations, we used a SOP stabilizer before the polarization beam splitter.

The SOP of both channels are checked and stabilized. The root-mean-square pilot tone is extracted and fed back to the electronic controller of the polarization stabilizer [8].

A single demultiplexed channel (which contains 2 AP-DCDM channels) is detected by an avalanche photodiode (APD) and passed through the AP-DCDM Clock-and-Data-Recovery (CDR) unit to extract the AP-DCDM channel 1 and channel 2 [1, 2].

As shown in Figure 1, by using a filtered amplified spontaneous emission (ASE) source and variable optical attenuator (VOA) a variable amount of ASE noise is added to the demultiplexed signal in order to change the optical signal to noise ratio (OSNR). For this measurement, we used Optical Spectrum Analyzer with resolution of 0.5 nm.

The performance of 20 Gbit/s AP-DCDM-PolDM is examined over fiber lengths from 0 km to 180 km.

Due to low lunch power the effect of nonlinearities are negligibly small.

III. RESULT AND DISCUSSION

The PolDM-AP-DCDM system at aggregated bit rate of 20 Gbit/s with the SOP stabilizer is evaluated. We have measured the BER as a function of the single demultiplexed channel OSNR, which is detected after polarization demultiplexing.

Note that the input power to avalanche photodiode is fixed to -19 dBm. The performance of single channel transmission system is compared with the PolDM-AP-DCDM signal in the present and absence of SOP stabilizer.

Figure 2 reports the bit error rate curves versus optical signal noise ratio over back to back, 125 km and 180 km SSMF length. The 20 Gbit/s AP-DCDM-PolDM results (PolDM-APDCDM_SOP Stabilizer ON) refer to the channel tagged using a pilot tone, which has a worse performance than another channel. These BER curves are compared with 10 Gbit/s single user, when stabilizer is on (1CH-APDCDM_SOP Stabilizer On), off (1CH-APDCDM_SOP Stabilizer Off) and the pilot tone.

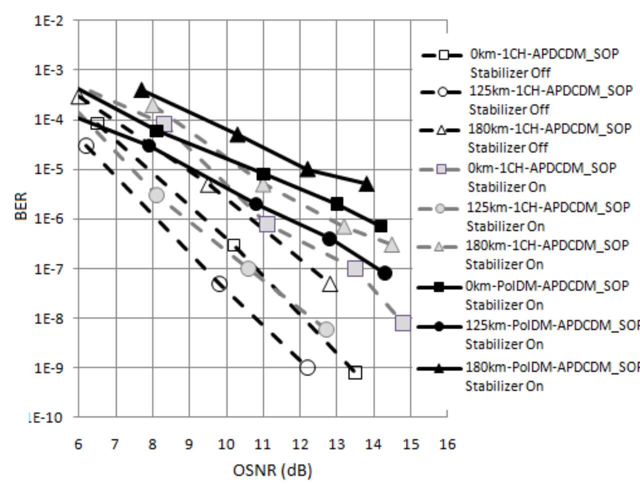

Figure 2. Bit Error Rate versus Optical Signal Noise Ratio for different lengths of standard single mode fiber. Measures are performed for PolDM-AP-DCDM system at 20 Gbit/s when the SOP stabilizer is on (black marker) and for single channel system at 10 Gbit/s (no SOP stabilizer) (open markers) and for single channel system at 10Gbit/s with a SOP stabilizer (gray market)

To realize a SOP stabilizer effect on the AP-DCDM-PolDM performance. Figure 3 shows the effect of propagation length on OSNR at BER of 10^{-6} for single-channel system at 10 Gbit/s in a presence and absence of SOP stabilizer and for AP-DCDM-PolDM transmission at 20 Gbit/s in presence of stabilizer.

The penalty of ~ 1 dB is experienced by increasing the length from 0 km (back-to-back) to 180 km for the 10 Gbit/s single channel transmission when the SOP stabilizer is off. And a penalty of around 2 dB is experienced when the SOP stabilizer is active.

A penalty increases to around 2.8 dB when both orthogonally polarized channels are propagating. The penalty increases because of the non ideal performances of optical components in SOP stabilizer which cause the inter-channel crosstalk because of the limited polarization extinction ratio (~ 14 dB) of the SOP stabilizer.

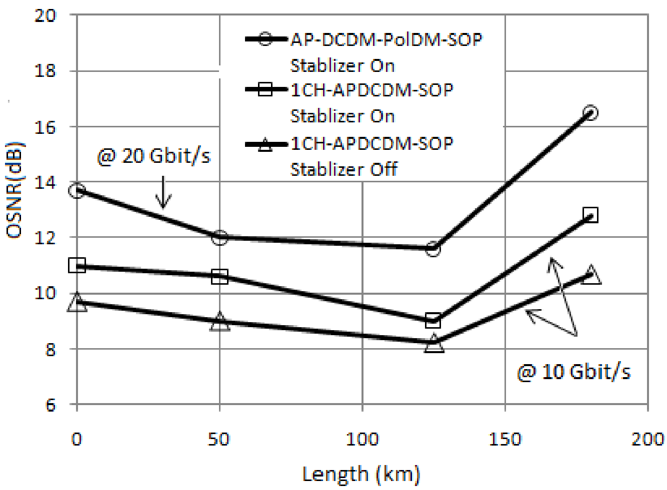

Figure 3. Optical Signal Noise Ratio for Bit Error Rate of 10^{-6} versus different standard single mode fiber length. Measures are performed for Polarization division multiplexing system at 20 Gbit/s when the SOP stabilizer is active, single-user system at 10 Gbit/s when the SOP stabilizer is off and single user system at 10 Gbit/s when the SOP stabilizer is on.

IV. CONCLUSION

Absolute Polar Duty Cycle Division Multiplexing over Polarization Division Multiplexing has been shown an alternative technique to double the bitrate, while preserving the 10 Gbit/s dispersion tolerance of the AP-DCDM format. The experimental performance demonstrate the capability of AP-DCDM-PolDM to provide transmission over 180 km of SSMF uncompensated fiber at an overall capacity of 20 Gbit/s. We have shown the effectiveness of an SOP stabilizer in an APDCDM-PolDM system.

Despite of coherent crosstalk between channels, a BER of less than 10^{-6} with tolerable penalties is achieved up to 180 km transmission length of SSMF without using any dispersion compensation techniques.

Based on the experimental results, it can be concluded that using AP-DCDM technique, more than one user can be carried over the same PolDM channel. Consequently, the capacity utilization of the PolDM channels can be increased.

REFERENCES

[1] A. Malekmohammadi, M.K. Abdullah, A.F., Abas and M. Mokhtar, “Analysis of RZ-OOK over Absolute Polar Duty Cycle Division Multiplexing in Dispersive Transmission Medium”, *IET journal of Optoelectronics*, vol. 3, pp. 197–206, 2009

[2] A. Malekmohammadi, G. A. Mahdiraji , A. F.Abas, M. K. Abdullah, M. Mokhtar and M. F. A. Rasid, “ Realization of High Capacity Transmission in Fiber Optic Communication Systems Using Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM) Technique”, *Optical Fiber Technology*, vol. 15, pp. 337-343, 2009

[3] A. Malekmohammadi, “20 Gbit/s Absolute Polar Duty Cycle Division Multiplexing-Polarization Division Multiplexing (AP-DCDM-PolDM) Transmission System” Proc. The Sixth International Conference on Systems and Networks Communications (ICED 2011), Aug.2011

[4] P. Boffi, M. Ferrario, P. Martelli, P. Parolari, A. Righetti and R. Siano, “20-Gb/s PolDM Duobinary transmission over 350-km ssmf supported by a polarization stabilizer and an optical dispersion compensator,” *IEEE Photon.Technol. Lett.*, vol. 20, pp. 1118–1120, Jul. 2008.

[5] M. I. Hayee, M. C. Cardakli, A. B. Sahin, and A. E.Willner, “Doubling of bandwidth utilization using two orthogonal polarizations and power unbalancing in a polarization-division-multiplexing scheme,” *IEEE Photon.Technol. Lett.*, vol. 13, no. 8, pp. 881–883, Aug. 2001.

[6] J. Toulouse, “ Optical Nonlinearities in Fibers: Review, Recent Examples, and System Applications” *Journal of Lightwave Technologies*, vol. 23, no. 11, pp. 3625-3639, 2005.

[7] H. Kim and R.-J. Essiambre, “Transmission of 8 × 20 Gb/s DQPSK signals over 310-km SMF with 0.8-b/s/Hz spectral efficiency,” *IEEE Photon. Technol. Lett.*, vol. 15, no. 5, pp. 769–771, May 2003.

[8] M. I. Hayeei, M. C. Cardakli, “Doubling of Bandwidth Utilization Using Two Orthogonal Polarizations and Power Unbalancing in a PolDM Scheme,”IEEE Photonic Technology Letter , Vol. 13, No. 8, pp/ 881-883, 2001.

[9] P. Winzer and R. Jean, Advance modulation formats for high-capacity optical transport networks, *J. Lightwave Technol*. vol. 24, pp. 4711–4728, 2006.