Reduction of Optical Beat Noise in Optical Sampled Subcarrier Multiplexing Systems Using Polarization Interleaved-OTDM technology

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Abstract- **An enhanced optical sampled subcarrier multiplexing scheme using polarization interleaving in optical subcarrier multiplexing networks is proposed and experimentally demonstrated for distortion reduction and optical beat interference (OBI) suppression. By using the proposed polarization interleaving scheme, a system can employ a lower-cost broad pulse source (50 ps) and achieve comparable performance, in terms of carrier-to-noise ratio (CNR) and composite triple beat (CTB), to the prior scheme using narrow pulse source (3 ps). The proposed scheme significantly enhances the chromatic dispersion tolerance, thus alleviating the OBI caused by the pulse overlapping.**

I. INTRODUCTION

Optical subcarrier multiplexing (SCM) has been widely used for multi-channel analog video distribution [1] over optical fiber. It has also found applications in cellular networks [2] and even in high-speed data communications [3]. One of the major obstacles in optical SCM system is the inter-modulation distortion (IMD) caused by the nonlinearity in various optical and electrical components in the system. A distortion reduction technique, called optical sampled subcarrier multiplexing (OS-SCM), based on optical time-division multiplexing (OTDM) and optical sampling has been proposed [4]. By distributing the SCM subcarriers into several OTDM sampling channels such that each channel carries only a portion of subcarriers, IMD can be reduced substantially. The combined SCM signals for one OTDM channel are optically sampled by modulating the optical pulse source with the SCM signals. To avoid OBI, it is desirable to use an optical pulse source with narrow pulse width, for instance, mode-locked fiber lasers or mode-locked semiconductor lasers.

To further enhance the performance and cost-effectiveness, we propose and investigate a novel scheme using polarization interleaved-OTDM. The proposed scheme allows the use of optical pulse source with much wider pulse width, which can be achieved by optical pulse carving using an intensity modulator or by others such as gain-switching lasers. Thus the transmitter cost can be significantly reduced. The OTDM channels are separated into two groups with orthogonal polarizations. With polarization interleaving, the OBI due to the pulse overlapping by the adjacent OTDM channels from chromatic dispersion can be reduced substantially. One unique feature of the proposed scheme is that polarization de-multiplexing is not required at the receiver side as OTDM demultiplexing will filter out other OTDM channels. As expensive polarization tracking system is not needed, it also markedly reduces the complexity of the receiver implementation. In this paper, we experimentally showed that the performance, in terms of CTB and CNR, achieved by using the newly proposed scheme with a 50-ps pulse source is comparable to that in a 3-ps pulse OS-SCM system. This shows that the proposed scheme greatly improves the tolerance of the chromatic dispersion, thus, keeping the receiver complexity and the implementation cost low. To characterize the tolerance of wider pulse width of the proposed scheme, an experiment was conducted to compare the performance of the proposed scheme and the original OS-SCM scheme when 50-ps pulse source is used. A serious degradation (around 10 dB) in CNR was observed in the OS-SCM scheme which does not employ polarization interleaving. In this paper, we first describe the proposed PI-OTDM scheme in section II. The experimental setup and results are shown in section III. Section IV concludes this paper.

II. PROPOSED PI-OTDM SCHEME

Among all the nonlinear distortions, the third-order IMD is the most difficult to tackle as it can lie directly within the frequency band of SCM channel. For the second-order distortion, it can be avoided if the intensity modulator is biased properly to achieve an odd transfer function. It has been shown that the number of third-order IMD is proportional to N^2 for an N-channel SCM system [5]. In view of this, a distortion reduction scheme was proposed to offload subcarrier channels by using optical sampling and OTDM technique [4]. The principle is to create a number of time-domain channels within one single wavelength. Subcarrier frequencies are then distributed over these time domain channels. Illustrated in Fig 1(a), subcarrier channels to be transmitted are divided into several groups. The assignment of frequencies in each group can follow a fixed-frequency-spacing approach or specialized algorithms that were previously implemented in [6]-[7] to yield further distortion reduction. An optical short pulse source is used to generate high repetition rate optical pulse train, which acts as the carrier for subcarrier signals. However, the pulsewidth broadens quickly with transmission distance due to chromatic

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dispersion, and the broadened pulses cause OBI between adjacent time-domain channels during multiplexing. This makes the signal fluctuate greatly and results in serious CNR degradation.

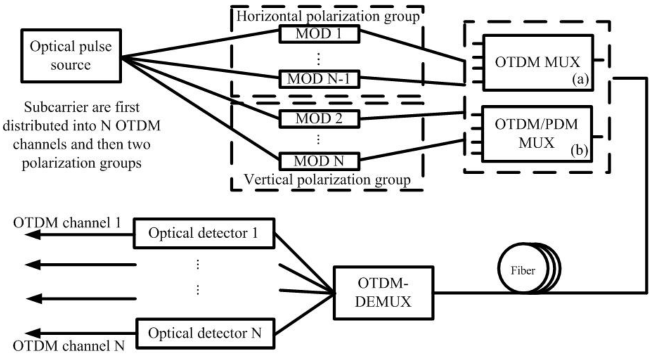

Fig. 1: (a) OS-SCM scheme and (b) PI-OTDM scheme.

In order to increase the chromatic dispersion tolerance to allow the use of broad optical source for the OS-SCM scheme, we propose to separate the OTDM channels into two groups with orthogonal polarizations to suppress OBI. The principle of the orthogonal polarization interleaving OS-SCM is illustrated in Fig. 1(b). Subcarriers are distributed to *N* OTDM channels. The odd and even OTDM channels are further grouped into two orthogonal polarization groups. Since the adjacent pulses lie on different polarization states, broadening of pulse will only cause overlapping in time but not OBI at the detector. This provides multifold advantages, including higher tolerance in chromatic dispersion and better utilization of bandwidth as a broader pulse is used. One important feature of the proposed scheme is that the receiver complexity is low as OTDM demultiplexing is performed directly to separate OTDM without polarization demultiplexing. No costly polarization demultiplexing and polarization tracking system is required. We refer to the previous [4] and this proposed polarization interleaving scheme as "OS-SCM" and "PI-OTDM" respectively. The difference is that the latter uses a polarization beam combiner (PBC) instead of a coupler to combine the two groups of signals.

III. EXPERIMENTAL SETUP AND RESULTS

A. 50-ps PI-OTDM vs. 3-ps OS-SCM

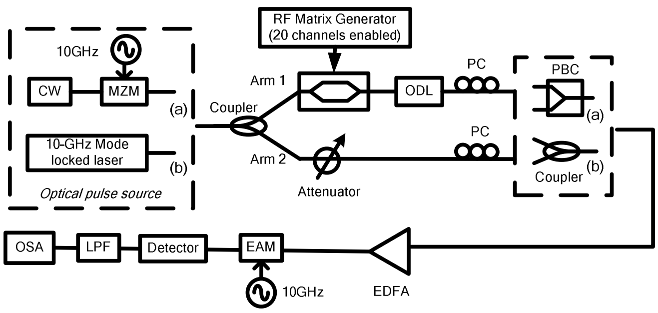

Fig. 2: Experimental setup for (a) OS-SCM and (b) PI-OTDM schemes in 40-channel system using 50-ps pulse source.

Fig. 2(a) shows the experimental setup used to investigate the performance of the proposed PI-OTDM scheme in a 40-channel system. A 50-ps optical pulse train with 10-GHz repetition rate was first generated by modulating a Mach-Zehnder Modulator (MZM) with 10-GHz sinusoidal wave. The pulse train was then split into two arms. 40 subcarriers were divided into two OTDM channels, i.e. N=2 in this case, according to fixed-frequency-spacing approach. Since fixed-frequency-spacing approach was used, the third-order IMD generated from the subcarriers on one OTDM channel would not fall into the frequency band of another OTDM channel. Due to the limited number of matrix generator available, only Arm 1 was modulated by a matrix generator with 20 (half of 40) RF carriers as in [4]. Albeit Arm 2 was left unmodulated, OBI between the adjacent OTDM channels, if any, still existed and could be evaluated. The modulation index of each channel in Arm 1 was set at about 5%. An optical delay line (ODL) was inserted in Arm 1 to adjust the relative delay between the two arms for time multiplexing. A PBC was used and tuned so that the same amount of power from the two arms passed through the PBC. For the 3-ps OS-SCM setup, as illustrated in Fig. 2(b), the conventional 50-ps pulse source is replaced by a 10-GHz mode-locked laser with 3-ps pulsewidth. A coupler instead of a PBC was used to time-multiplex two OTDM channels to form a single 20G-sample/s OTDM signal.

The setups at the receiver side of both schemes are the same. An electro-absorption modulator with 22-dB extinction ratio was driven by a 10-GHz sinusoidal wave to demultiplex the OTDM channels. The output power after demultiplexing was kept at −10 dBm. The CNR and composite-triple-beat (CTB) were measured by an RF spectrum analyzer.

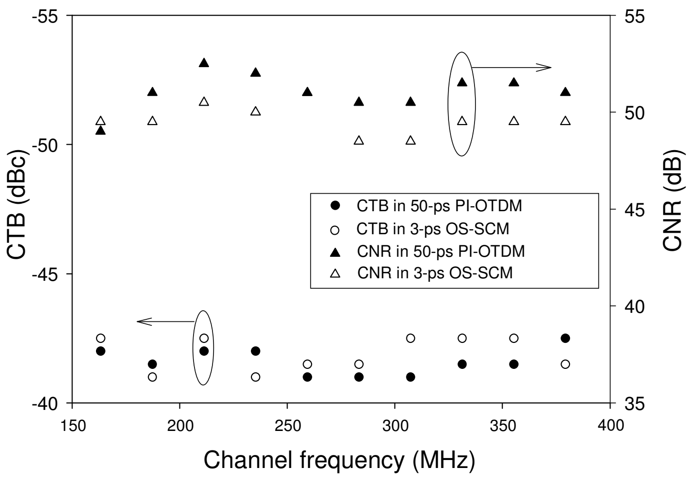

Fig. 3. Measured CTB and CNR in PI-OTDM with 50-ps pulse source (solid) and OS-SCM systems with 3-ps pulse source (hollow)

The experimental results for 50-ps PI-OTDM and 3-ps OS-SCM cases are compared and illustrated in Fig. 3. The performance difference, in terms of both CTB and CNR, is negligible. This demonstrates that when polarization interleaving is employed, we are able to use much wider pulse width without degrading CNR and CTB. That is, the newly proposed PI-OTDM scheme significantly enhances the chromatic dispersion tolerance of the prior OS-SCM scheme.

B. 50-ps PI-OTDM vs. 50-ps OS-SCM

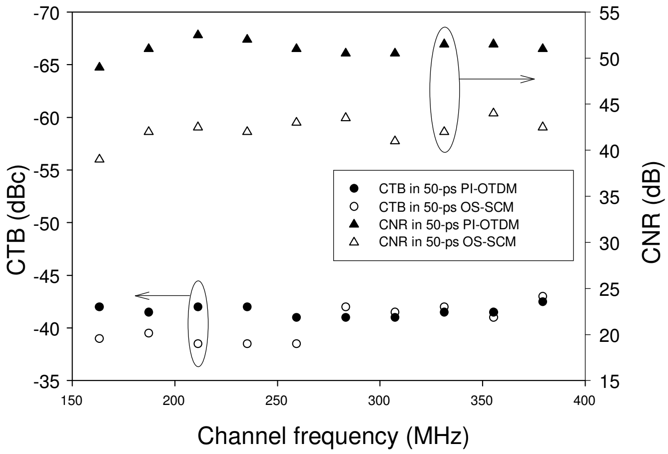

Fig. 4. Measured CTB and CNR in PI-OTDM with 50-ps pulse source (solid) and OS-SCM with 50-ps pulse source (hollow)

The performance comparison between 50-ps PI-OTDM and 50-ps OS-SCM was also conducted experimentally. The experimental setup of 50-ps OS-SCM scheme is similar to that in Fig. 2. The only difference is that the PCs were tuned until maximum beating was observed in the RF spectrum at the receiver side. It is worth to note that, in the 3-ps OS-SCM scheme, no beating can be observed no matter how the PCs are turned as the pulse is narrow enough for the isolation between adjacent OTDM channels.

Both CTB and CNR of 10 out of the 20 channels in Arm 1 were measured and the results are shown in Fig. 4. CTB for both OS-SCM and PI-OTDM schemes remain almost the same throughout the frequency range. Meanwhile, the OS-SCM scheme shows about 10-dB degradation in CNR when compared with that of the PI-OTDM scheme. We verify that polarization interleaving provides stable performance and better CNR when a pulse source with broader pulse width is used. The RF spectra of the demultiplexed signal at 235.25 MHz from RF spectrum analyzer are shown in Fig. 5 and Fig. 6 for the OS-SCM and PI-OTDM schemes, respectively. It can be observed that the noise level in OS-SCM system is about 10 dB higher than that in PI-OTDM, showing the performance improvement in CNR by the proposed PI-OTDM scheme.

IV. CONCLUSION

We proposed and experimentally demonstrated a novel and more cost-effective polarization interleaving OTDM scheme in optical SCM networks that further suppresses OBI. No polarization demultiplexing is required. The scheme provides higher tolerance against chromatic dispersion or allows the use of broader pulse source that is less expensive. With the proposed scheme, the system with 50-ps pulse source achieve comparable CTB and CNR performance to that of the previous scheme using 3-ps pulse source. To characterize the tolerance of wider pulse width of the proposed scheme, an experiment was conducted to compare the performance of the newly proposed scheme and the prior OS-SCM scheme when 50-ps pulse source is used. Around 10 dB degradation in carrier-to-noise ratio (CNR) was observed in the OS-SCM scheme.

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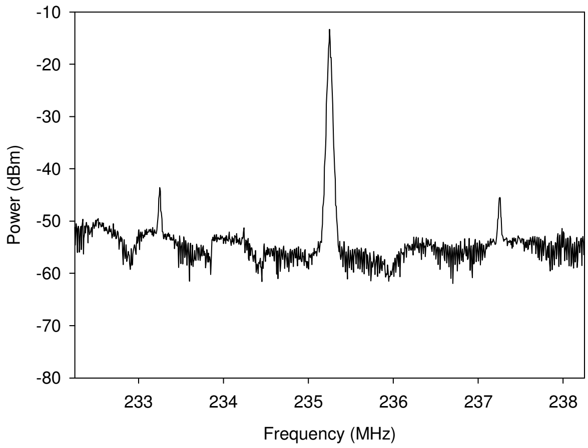

Fig. 5. Spectrum at 235.25 MHz measured in an OS-SCM system using 50-ps pulse source.

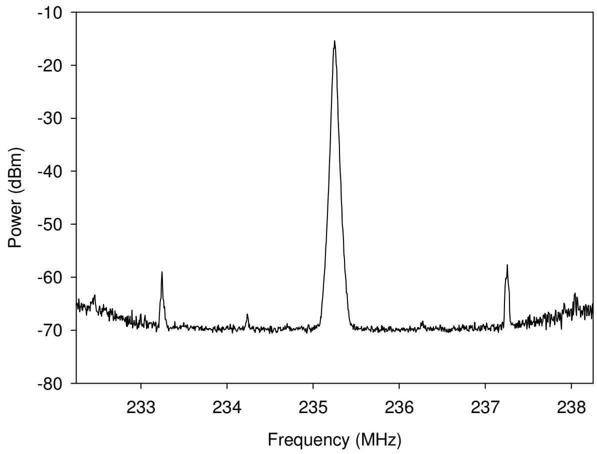

Fig. 6. Spectrum at 235.25 MHz measured in an PI-OTDM system using 50-ps pulse source.

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