Ultra-wideband 40-GHz optical-combs generation and distribution through WDM optical fiber networks

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Abstract— **A stable 40 GHz-spacing optical-combs are generated using a single supercontinuum source pumped by an optically multiplexed 40 GHz, 2-ps mode-locked semiconductor laser diode. A distribution over the 80 km WDM fiber link of more than 80 lines of 40 GHz-spacing optical-comb ranged from 1533 nm to 1610 nm, which cover the C- and L-band in the WDM optical fiber networks, are experimentally demonstrated.**

I. INTRODUCTION)

A demand for the stable optical clock distribution over the existing wavelength division multiplexing (WDM) networks is rapidly emerging. With increasing the numbers of WDM channels, the total cost of signal sources and their center optical frequency stabilization expands rapidly. For the cost reduction and the great ease of relative optical frequency spacing control, a multi-carrier generation from a single supercontinuum (SC) source has been proposed [1,2].

In this paper, we report a simple configuration of a stable 40 GHz-spacing optical-comb generation using an external cavity hybrid mode-locked semiconductor laser and a nonlinear fiber. A 40 GHz-spacing optical-combs are divided into 100 GHz spacing WDM channels and transmitted through a WDM fiber link. A 40 GHz-spacing optical-combs are distributed in all the WDM channels covering the C-, and L-band (1533 – 1610 nm).

II. EXPERIMENTS AND DISCUSSIONS

As the original source, an external cavity, hybrid mode-locked semiconductor laser (MLLD) was used. The laser produced a 10 GHz repetition rate, 1.5 ps width pulse trains at 1530.33 nm. A precise controllable optical multiplexer integrated as a planar lightwave circuit was used to produce a 40 GHz repetition rate pulse train as shown in Fig.1. In an optical time-delayed multiplexing, the optical carrier phase of each delayed pulse could be changed by from 0 to π using the optical phase shifters, resulting in a precisely controllable multiplexing. As shown in Fig. 1, both a normal return-to-zero (RZ) multiplexing with the same optical carrier phase and a carrier suppressed return-to-zero (CS-RZ) multiplexing with the π phase shift in the adjacent pulse could be produced using this multiplexing technique.

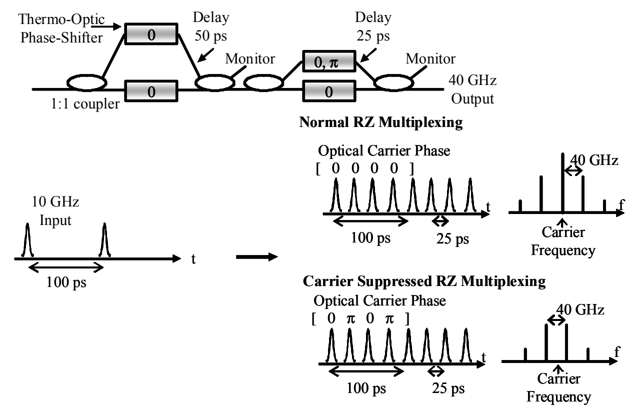

Fig. 1: 10-to-40 GHz multiplexing using a time-delayed optical multiplexer with optical phase shifters.

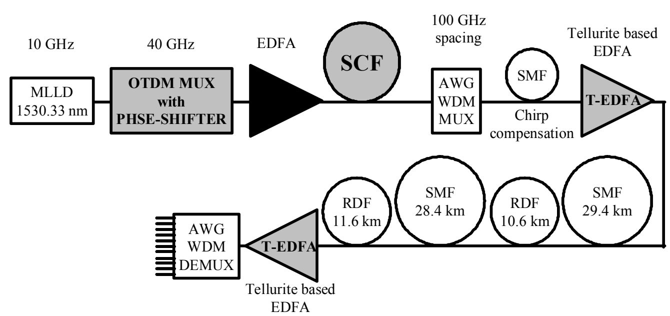

Fig. 2: Experimental setup.

Figure 2 shows the experimental setup of 40-GHz optical-combs generation and distribution over the 80 km fiber link. Wideband 40 GHz spacing optical combs generation was performed by SC generation directly pumped by a 40 GHz pulse train. Because the SC is generated by frequency chirping accumulation by nonlinear propagation in a normal dispersion fiber [3], no coherent degradation occurs and the relative phase between the adjacent pulses is conserved [4].

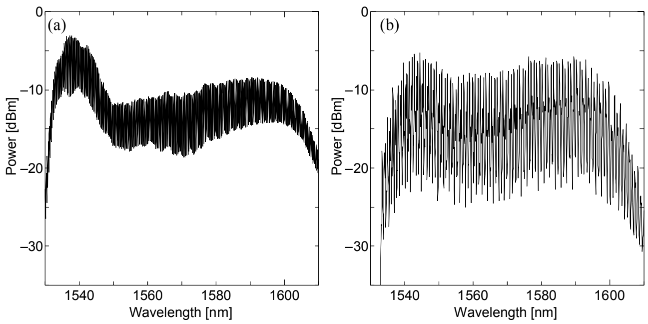

Fig. 3: Optical spectra of (a) 40 GHz spacing optical combs and (b) spectrum sliced optical combs.

By spectrum slicing using a pair of 100 GHz spaced arrayed waveguide grating (AWG), 40 GHz spacing optical combs were separated into the all WDM channels in the 100 GHz spacing dense WDM system. The merit of this method is a simultaneous 40 GHz clock distribution from a single optical source. The clock in each WDM channel is strictly locked by the microwave locking frequency of the source laser with timing jitter less than 0.4 ps. A much more stabilized optical clocks will be able to be obtained by using such method as proposed in [5].

As the optical amplifier, Tellurite based EDFAs (T-EDFAs) were used for broadband signal amplification and spectrum. The transmission line was two pairs of a single mode dispersion fiber (SMF) and a reversed dispersion fiber (RDF). The total length is 80 km and the average zero dispersion wavelength is 1546.59 nm and the dispersion slope is 0.0087 ps/nm/km. After amplified by a T-EDFA, transmitted 40 GHz optical clock was recovered using a 50 GHz bandwidth photo-diode and measured the timing jitters.

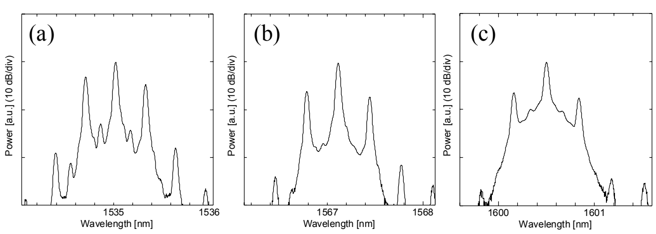

Fig. 4: Optical spectra after 80 km transmission at (a) 1535. 04 nm, (b) 1567.13 nm, and (c) 1600.60 nm.

Figure 3(a) shows the spectrum of SC at the output of SCF. 40 Ghz spacing optical combs were generated from 1530 nm to 1610 nm. Fig. 3(b) shows the spectrum sliced 40 GHz optical combs. Figure 4(a)-4(c) show the measured optical spectra after 80 km transmission at 1535. 04 nm, 1567.13 nm, and 1600.60 nm, respectively. It is clearly shown that 40 GHz optical clocks were distributed in WDM channels. And measured timing jitters were less than 0.5 ps.

III. CONCLUSION

A precise 10-to-40 GHz multiplexing was obtained using a time-delayed optical multiplexer with phase shifters. 40 GHz spacing optical combs were generated by supercontinuum generation with less than 0.4ps timing jitter. Simaltaneous 40 GHz optical clocks were generated by spectrum slicing in all WDM channels. And finally, 40 GHz optical clocks were distributed through 40 Gbit/s based DWDM transmission link with less than 0.5 ps timing jitter.

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