1.28 Tbaud Nyquist-OTDM Transmission over a 7-Core Fiber Using an On-Chip SDM Coupler

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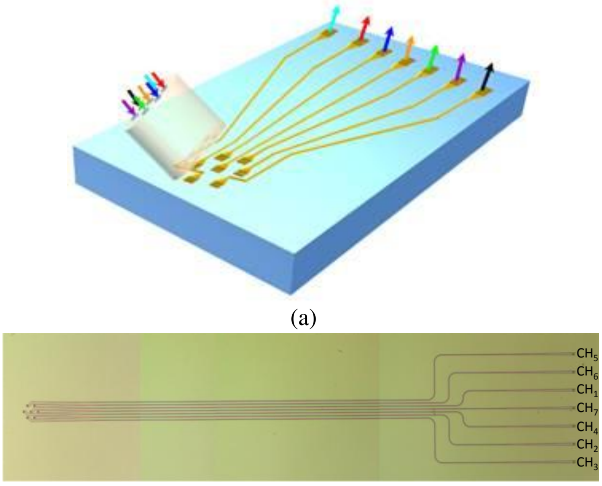
Abstract Summary
We have demonstrated the first 1.28-Tbaud Nyquist-OTDM-SDM transmission over a 67.4-km seven-core fiber with an aggregated data rate of 7.2 Tbit/s using a silicon SDM coupler. 10-GHz control pulses were transmitted through the center core.

Introduction
Optical time division multiplexing (OTDM) has been used to demonstrate record-high serial bit rates with a record symbol rate of 1.28 Tbaud [1-4]. Traditional OTDM relies on short pulses, which usually occupies a large bandwidth in the frequency domain and makes it less spectral efficient. Recently, Nyquist OTDM (N-OTDM) was proposed, enabling both high serial bit rate and high spectral efficiency [4-6]. To further increase the single carrier bit rate and spectral efficiency, space division multiplexing (SDM) can be used [7].

In this paper, we demonstrate the first transmission of a 1.28 Tbaud Nyquist-OTDM signal over a 67.4-km seven-core fiber, at an aggregated data rate of 7.2 Tbit/s (6 SDM × 1.2 Tbit/s) within a bandwidth of only 13 nm. A silicon CMOS-compatible SDM coupler is used to de-couple from the seven cores. Each of the 6 outer cores carries the 1.2 Tbit/s Nyquist-OTDM DPSK signal and the center core carries the control pulse used in the time-lens based OTDM demutiplexer.

On-chip Grating Coupler Array for SDM Coupling
A silicon-on-insulator (SOI) chip enables coupling between a 7-core fiber and 7 standard single mode fibers (SSMFs), as shown in Fig. 1. The device was fabricated on a commercial SOI sample with top silicon thickness



(a)

(b)

Fig. 1. (a) Schematic of the on-chip SDM coupler; (b) Top view of the fabricated device.

of 250 nm and buried silicon dioxide (BOX) of 3 μm. The detailed fabrication process can be found in Ref. [8]. The layout of the output grating couplers corresponds to that of the cores of the multicore fiber (MCF), with the same core pitch of 49 μm. The devices shows coupling loss as low as 6.8 dB with 3 dB bandwidth of 48 nm and less than 3 dB coupling loss variation between all spatial channels.

Experimental Setup and Results
Fig. 2 shows the schematic of the experimental setup for the 1.28 Tbaud Nyquist-OTDM transmission over a 7-core fiber, which consists of a 1.28 Tbaud Nyquist-OTDM signal transmitter, a control pulse generator, a 67.4-km seven-core fiber, a free-space fan-in device, a

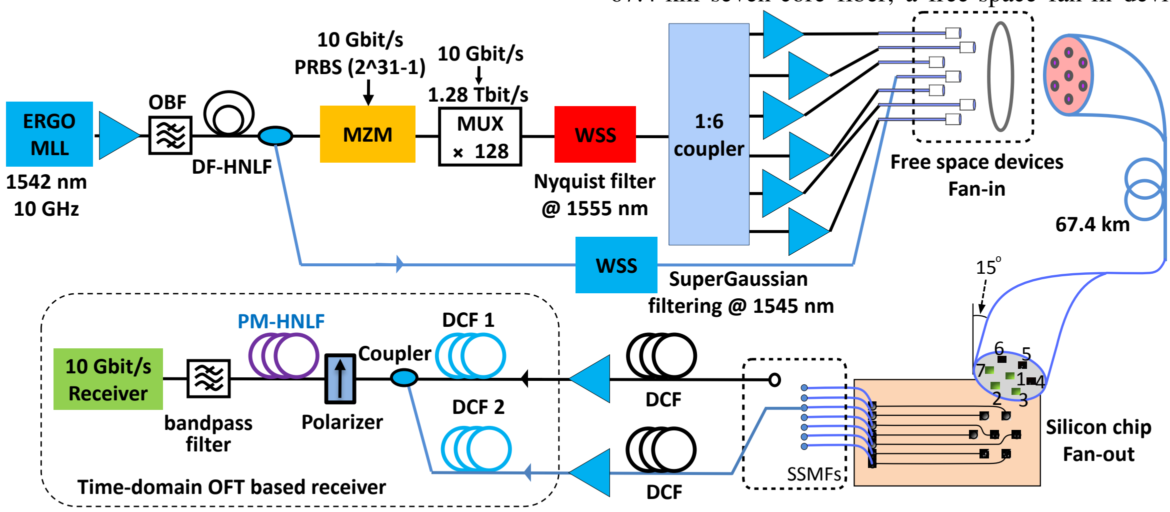


Fig. 2. Schematic of the experimental setup for the 1.28 Tbaud Nyquist-OTDM transmission over a 7-core fiber.

SOI chip for multicore fan-out, a TD-OFT based serial-to-parallel converter and a 10 Gbit/s direct detection receiver. An erbium glass oscillating mode-locked laser (ERGO-MLL) produces 10-GHz pulses (1542 nm and 1.5-ps FWHM), which are used to generate an optical frequency comb source based on the SPM in a DF-HNLF [7]. A part of the comb source is super-Gaussian filtered at 1545 nm with a FWHM of 1.6 THz using a wavelength-selective switch (WSS) to generate the control pulse. The other part is modulated by 10-Gbit/s DPSK data in a Mach-Zehnder modulator (MZM). The modulated 10 Gbit/s RZ-DPSK signal is multiplexed in time using a passive fiber-delay multiplexer (MUX ×128) to generate a 1.28 Tbit/s RZ-OTDM signal, which is then Nyquist filtered at 1555 nm with a roll-off of 0.5 to the resulting 1.28 Tbit/s Nyquist-OTDM signal, corresponding to a net rate of 1.2 Tbit/s after subtracting the 6.6 % overhead for forward error correction (FEC) [4, 9]. 6 SDM channels were generated using splitters and amplifiers and then launched into the 6 outer cores of the 67.4-km seven-core fiber through the free-space fan-in device with a launched power of 20 dBm/core. The control pulses were launched into the center core with a launched power of 17 dBm for the OTDM demultiplexing in the receiver. The seven-core fiber has a cladding diameter, a cladding thickness and a core pitch of around 196 µm, 49 µm and 49 µm, respectively [7, 10].

After the transmission in the seven-core fiber, the data signals and the control pulses were spatially demultiplexed using the on-chip grating coupler array. The spectra after the transmission are shown in Fig. 3. Each of the spatially demultiplexed SDM channels was measured individually. The selected channel was first dispersion compensated by a 10.8 km long dispersion compensating fiber (DCF, D= -128 ps/nm/km), and then launched into the TD-OFT based OTDM receiver. The transmitted control pulses were dispersion compensated by another DCF, then launched into the TD-OFT acting as pump pulses.

The time lens based TD-OFT can be used for time-to-frequency mapping (or serial-to-parallel conversion) [4, 7, 11-12]. The received 1.28 Tbaud Nyquist-OTDM signal is converted into an OFDM signal with large subcarrier spacing. Since the frequency spacing

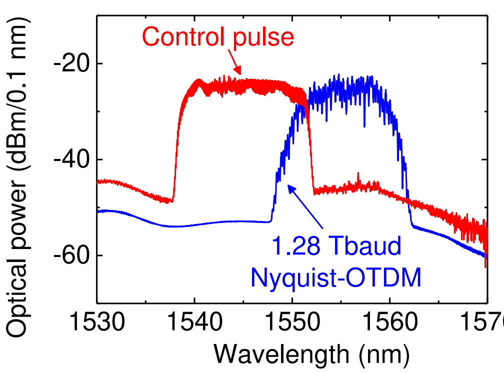


Fig. 3 Optical spectra of 10 GHz control pulse and 1.28 Tbaud Nyquist-OTDM signal after the MCF transmission.

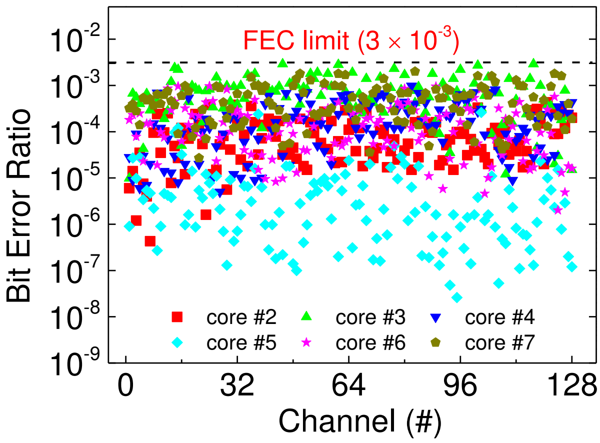


Fig. 4 BER measurements of all the SDM and OTDM tributaries after the MCF transmission.

(100 GHz) is much larger than the symbol rate (10 Gbaud), an OBF with a bandwidth of 40 GHz can be used directly to extract the subcarriers. The extracted 10 Gbit/s DPSK tributaries are directly detected using a delay-interferometer and a balanced detector.

Fig. 4 shows the measured bit error ratios (BERs) of 6 × 1.28 Tbit/s N-OTDM-SDM tributaries after the seven-core fiber transmission. The BERs varies with different cores, mainly due to the slightly different coupling loss for different spatial channels. All the SDM and OTDM tributaries has a BER below 3 x 10^{-3}, i.e. below the FEC threshold for all channels, thus confirming a successful transmission at an aggregated data rate of 7.2 Tbit/s, after subtracting the 6.6 % FEC overhead.

Conclusions

We have, for the first time, demonstrated a 1.28 Tbaud Nyquist-OTDM-SDM signal transmission over a 67.4-km seven-core fiber using a SOI SDM-demultiplexer. At an aggregated data rate of 7.2 Tbit/s, all the SDM and OTDM tributaries show a BER below the FEC threshold.

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