1.25 Gbit/s transmission of optical FFH-OCDMA signals over 80 km with 16 users

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Abstract: Encoding/decoding of FFH-OCDMA signals from 16 users is performed with Bragg grating arrays. Transmission of the multiplexed signals is demonstrated over 80 km of standard fiber at data rate exceeding 1 Gbit/s using dispersion compensating modules.

OCIS codes: (060.4510) Optical communications, (060.2340) Fiber optics components

1. Introduction

Several optical code division multiple access (OCDMA) systems have recently been proposed to manage the complex access problems associated with highly interconnected networks [1-10]. Direct sequence or time domain encoding has been demonstrated using delay lines or sampled Bragg gratings [1-2]. Frequency encoding of broadband or short pulse source has also been investigated using free space spectral slicing, chirped fiber gratings or fiber interferometers [3-6]. However, with the exception of the demonstration of simultaneous transmission of 12 users at 100 Mbit/s reported by Pfeiffer et al. [4], most experimental studies have measured the auto-correlation and the cross-correlation traces from one user/one interferer scenario.

Encoding in both the time and frequency domains, an approach referred to as Fast Frequency Hopping (FFH), offers greater flexibility in the choice of optical codes and results in an increased system capacity. Time and frequency spreading using pass-band filters and delay lines was first studied by Tanceveski and Andronovich in 1996 [7]. Since then, many hybrid (time and frequency) encoders have been considered including arrayed waveguide grating (AWG) cascaded by parallel optical delay lines [8,9]. In 1997, we proposed to use Bragg grating arrays (BGA) as encoders/decoders for FFH-OCDMA [10-11]. In this paper, we experimentally demonstrate the feasibility of this encoding/decoding principle. Furthermore, we show that FFH-OCDMA with BGA encoders can accommodate a large number of users, sixteen in the present case, and transmission rates exceeding 1 Gbit/s. The signals, transmitted over more than 80 km of standard fiber, were adequately decoded provided that appropriate chromatic dispersion compensation was performed.

2. Description of the system

The design of the encoders/decoders is critical to the performance of the FFH-OCDMA system. Each code is an ordered selection of eight frequencies chosen among a set of 30 frequency bands spaced by 50 GHz. We selected FFH-patterns corresponding to the family of Bin [12], which have the property that each code is a frequency-shifted copy of the other. This choice enables the use of a strain tunable decoder. In the present implementation, the individual grating length was 14 mm with 1 mm spacing and the total length of the BGA encoders/decoders were 11.9 cm. To operate with the minimum level of interference, the data rate is limited to 860 Mbit/s by the encoder length. Higher transmission rates are possible if two data pulses are allowed to be simultaneously present in the encoder. The chip duration is 150 ps as determined by the Bragg grating spacing. Writing of the encoders/decoders was performed with a Sagnac-type interferometer in order to obtain precise spacings, Bragg wavelengths and reflectivities [13]. The reflectivity and bandwidth of each individual grating were typically 13 dB and 20 GHz. The encoders consisted of 4 series, labeled s1 to s4 on Fig.1, of identically written BGA that were subsequently strain-tuned to different codes. More than 20 BGA (16 encoders + 4 decoders) were thus realized.

For the transmission experiment, amplified spontaneous emission (ASE) of an erbium-doped fiber amplifier (EDFA) is used as an incoherent broadband source (Fig. 1). An electro-optic modulator is used to generate the data stream from a 32 bit sequence of a pattern generator operating at 10 Gbit/s. Therefore, the incident 100 ps do not totally fill the chip time. Because only one modulator and data generator are available, the modulated pulses are then directed towards the 16 encoders through one 2:2 passive splitter, two circulators and two 1:8 passive splitters. An EDFA is placed at the output of each circulator in order to compensate for the spitting loss of 18 dB and

the coupling loss of the circulator (*i.e.,* a total of ≈ 20 dB). Note that the signal power suffers this loss twice because it has to be recombine after being reflected by each encoder. If each encoder used its own source, the signal would suffer this loss only once in a star network topology.

The modulated signals then propagate through 77.2 km of standard single mode fiber (SMF). The chromatic dispersion of the fiber link is compensated by a Dispersion Compensating Fiber module (DCF) having a dispersion of −1318 ps/nm and two additional EDFAs are needed to compensate the loss of these fibers (≈ 25 dB). At the receiver end, the signal is fed into a strain tunable decoder. The decoded signal, consisting of a sum of the desired user signal plus the interference contribution, is observed in a 30 GHz Communications Signal Analyzer.

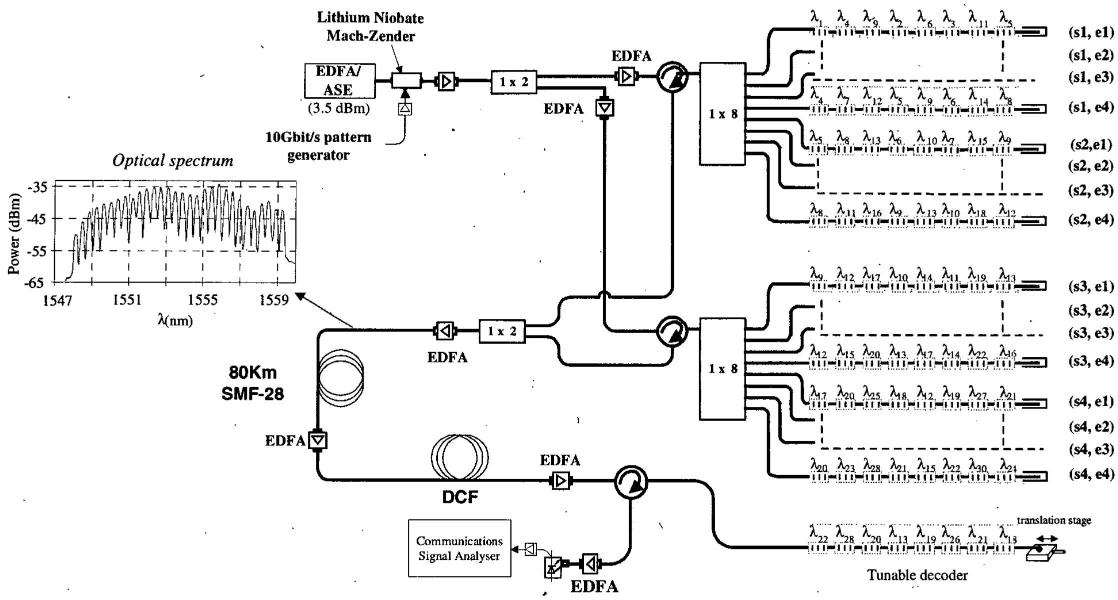

Fig. 1. Experimental setup for the transmission of FFH-OCDMA signals from 16 users through 80 km of fiber.

3. Results

Data transmission through the system is represented in Fig. 2. The broadband source is modulated at a data rate of 1.25 Gbit/s (Fig. 2a). The signal reflected from the 16 encoders is multiplexed in the transmission link. Fig 2b shows the temporal signal trace at the SMF fiber input and the optical spectrum is displayed in Fig.1 (total power 6.5 dBm). The back to back decoded signal is represented in Fig.2c. It can be seen that the pulses are broadened from 105 ps to 135 ps at the receiver, probably from the slight imperfections in the matching of the encoder/decoder delays and from the limited bandwidth of the individual gratings. The decoded signal after transmission through 80 km of SMF and the DCF module is represented in Fig. 2d. Comparison of Fig.2c and Fig.2d shows that the signal suffers little degradation from the transmission through the fiber link. The successive amplifications slightly reduces the S/N ratio. The data pulse are also broadened to 161 ps resulting in part from the residual dispersion of the link; the measured dispersion of the SMF (1456 ps/nm) being higher than expected. This however should not impact the system performance as the pulse width is still mostly confined within the chip duration of 150 ps. Although a BER measurement (currently underway) should be performed to completely characterized the transmission quality, we believe that this is the OCDMA transmission with the largest number of users ever performed. The data transmission rate was also increased to higher levels corresponding to several pulses simultaneously propagating in the encoder. Data transmission at 2.5 Gbit/s is represented in Fig.3 with the 16 transmitting users. The results indicate that the capacity of the system may be higher than was initially believed from the encoder length.

4. Conclusion

We investigated data transmission at 1.25 Gbit/s using an FFH-OCDMA system based on encoding/decoding performed with fiber Bragg grating arrays. The measured signals included the autocorrelation from the desired user code and the interference from 15 simultaneously transmitting users. The data was transmitted over 80 km of SMF fiber and recovered after adequate dispersion compensation. The results demonstrate that the FFH-OCDMA is a promising approach for multiple access high capacity networks.

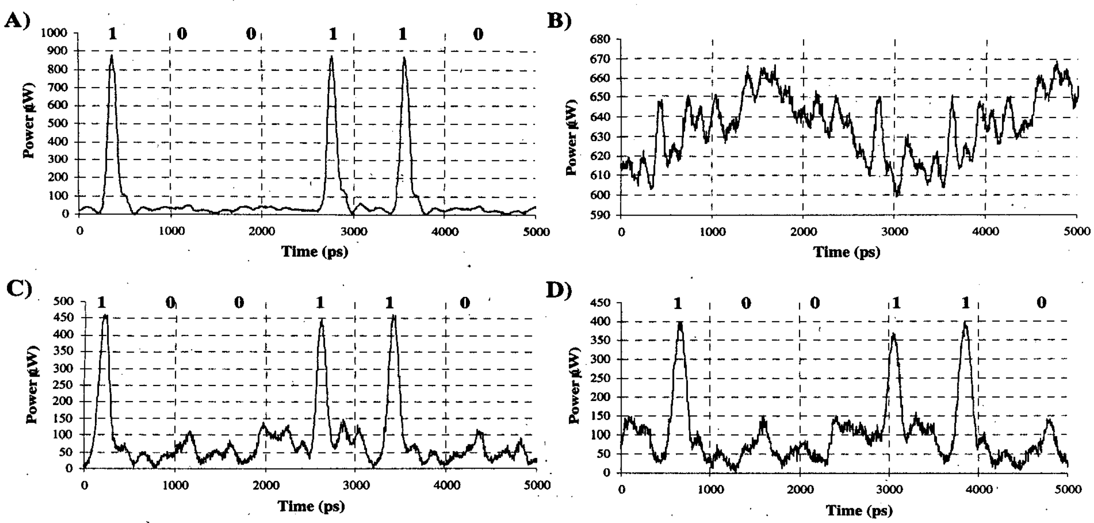

Fig. 2. A) Broadband data pulse after the modulator at a data transmission rate of 1.25 Gbit/s, B) multiplexed signals from the 16 encoders, C) decoded signal from user (s4,e2) without transmission through the SMF and DCF fiber, and D) decoded signal from user (s4,e2) after transmission through 80 km of SMF fiber and the DCF module.

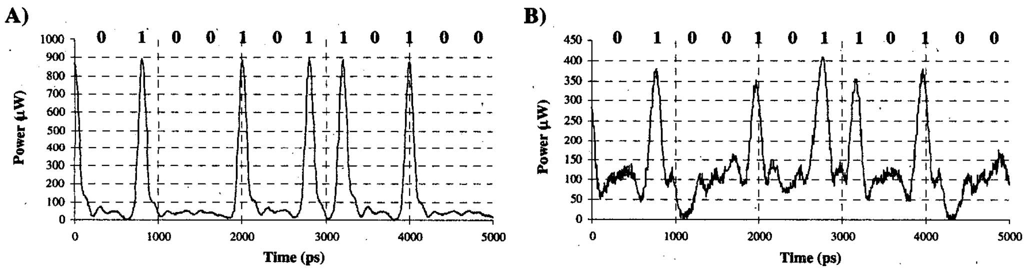

Fig. 3. A) Broadband data pulse after the modulator at a data transmission rate of 2.5 Gbit/s, B) decoded signal from user (s4,e2) after transmission through 80 km of SMF fiber and the DCF with 15 other users transmitting simultaneously.

6. References

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