Performance of a 1Gbps Optical Direct Sequence CDMA Based on Sampled Fiber Bragg Grating.

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ABSTRACT

This paper presents the experimental demonstration of a 1 Gbps Direct Sequence Optical Code Division Multiple Access (DS-OCDMA) system using pulsed coherent source. Encoding and decoding using Prime Sequence codes are achieved by Sampled Fiber Bragg Gratings (S-FBGs). The encoders/decoders have been designed with OptiGrating software and realized with Phase Mask Process. BER measurements have been performed in the asynchronous configuration when an interferer is delayed from the desired signal. A 2 dB penalty due to Multiple Access Interference effect (MAI) has been observed in the synchronous case. S-FBG technological limitations and optical interferences due to the source coherence time have been observed and will be discussed.

Keywords: Fiber Bragg Grating, Optical DS-CDMA, BER measurement, optical interferences, coherent source.

1. INTRODUCTION

The explosive growth of services (Data, video …) has placed increasing demand for high speed and large capacity communications in transmission systems. Actually, the last mile which can provides the link to business and residential customers is the most critical segment of any telecommunication network. The next generation last-mile or access networks will deliver various different services at the same time. Optical devices and passive optical networks (PON's) can provide sufficient bandwidth for such requirements. Several multiple access approaches have been proposed for this purpose as wavelength division multiplexing (WDM) and optical time division multiplexing (OTDM) or hybrid approach. While these approaches have been extensively explored and used in optical communication systems, alternatively, optical code division multiple access (OCDMA) is receiving increasing attention for next broadband access networks due to its potential information security, and asynchronous access capability [1] .

In the last few years, Fiber Bragg Gratings (FBG's) have been used to implement encoders/decoders for OCDMA applications [2,3,4,5,6]. FBG's constitute passive spectral filters and offer significant advantages such as ready integrability with all fiber optic systems, compactness and low fabrication cost.

The encoding can be performed either in time or in frequency domain. In the time domain, a signature or a code, composed by pulses referred as "chips", is attributed to each user to encode his data bits. The encoded bits are then broadcasted onto the network. They are decoded by users who have the appropriate signature. This technique is called Direct Sequence CDMA (DS-CDMA). In frequency domain, the overall spectral bandwidth is divided into small segments and the code information is contained in these segments. For example, in Frequency Hopping CDMA (FH-CDMA), the chips carrier frequency is changed according to a well defined code sequence that can once again be suitably identified by an appropriate receiver [7].

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Previous works in DS-OCDMA were presented using Optical Orthogonal Codes (OOC) and Prime Sequences (PS) [8,9]. Prime Sequences permit to improve the user multiplexing capacity and to reduce the code length while relaxing the Auto/Cross-correlation OOC constraints. These codes are constructed from a prime number "p" and characterized by a quadruple $(L,\_,\lambda_a,\lambda_c)$ where L denotes the sequence length, _ is the weight and λ_a , λ_c are respectively the maximum value of the out of phase auto-correlation function and maximum value of the cross-correlation function.

The paper is organized as follows. In Section 2, the Sampled Fiber Bragg Grating (S-FBG) design and realization is presented. Section 3 presents the experimental setup and the Bit Error Rate (BER) performances in presence of Multiple Access Interference (MAI), technological limitations and source coherence time influence on the system performances are discussed. Finally, conclusions are given in section 4.

2. SAMPLED FIBER BRAGG GRATING ENCODERS/DECODERS DESIGN AND FABRICATION

In our application, PS codewords C_1 (100010001) and C_2 (100100100) are implemented respectively by S-FBG devices. The code sequence is generated from the successive reflections of the Bragg Gratings (BGs) which compose a S-FBG. The C_1 and C_2 codes are generated from S-FBG$_1$ ($BG^1{}_1$, $BG^1{}_2$, $BG^1{}_3$) and S-FBG$_2$ ($BG^2{}_1$, $BG^2{}_2$, $BG^2{}_3$) devices writing at the Bragg wavelength λ_B =1551 nm. $BG^{i=1,2}{}_{j=1,2,3}$ represents the j^{th} 500µm length of Bragg gratings corresponds to the j^{th} "1" pulse chip in the i^{th} codeword. The "0" chips of the i^{th} codeword between two consecutive BG^i_j is represented by an optical fiber length.

The maximum mean optical power of each device is about 13%. To generate codewords composed by pulses with the same level, each BG is designed to present a different reflection rate, which compensates the incident wave depletion during its propagation through the S-FBG.

Encoders/decoders technological realization is achieved by UV photo-inscription of in-fiber Bragg Gratings with the Phase Mask Method. The length separating two successive BGs is controlled with an interferometric rule. The accuracy of the BG positioning is in the µm range.

The encoding is performed in the time domain as each pulse is transformed into a pulse train upon reflection from the different BGs. The temporal response of the encoders S-FBG$_1$ and S-FBG$_2$ are displayed in Fig. 1. The fourth small extra peak is due to secondary reflections between the three Fabry-Perot cavities involved in the design of the components. The train is then transmitted and decoded by the matched decoder device.

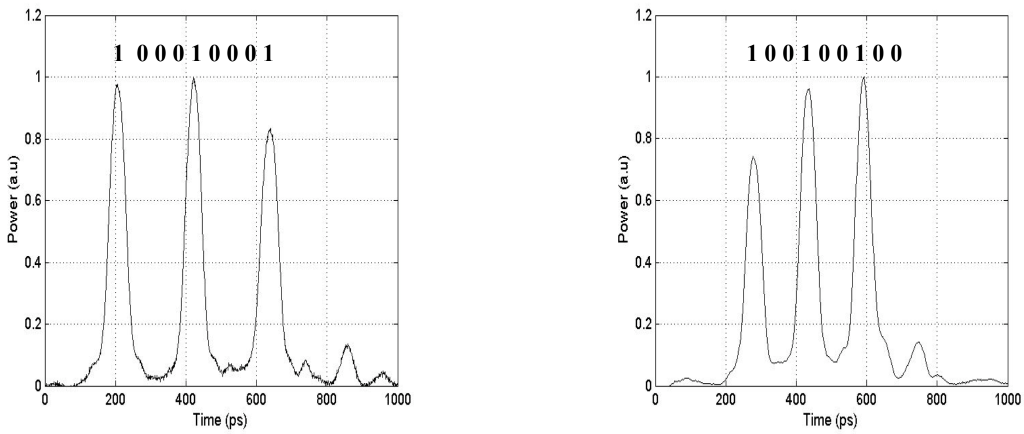

Figure 1. Prime Sequence codewords C_1 and C_2 generated by S-FBG$_1$ and S-FBG$_2$

3. CORRELATION AND BER PERFORMANCES

To estimate the performances of the proposed system, we have measured the auto and cross-correlation functions in two configurations. In Fig.2(a), the auto-correlation function (connected line) has been measured in single user configuration. The auto-correlation main peak corresponds to a matched decoding. The cross-correlation function (dotted line) shows that it is impossible to recover data bits with mismatched decoder.

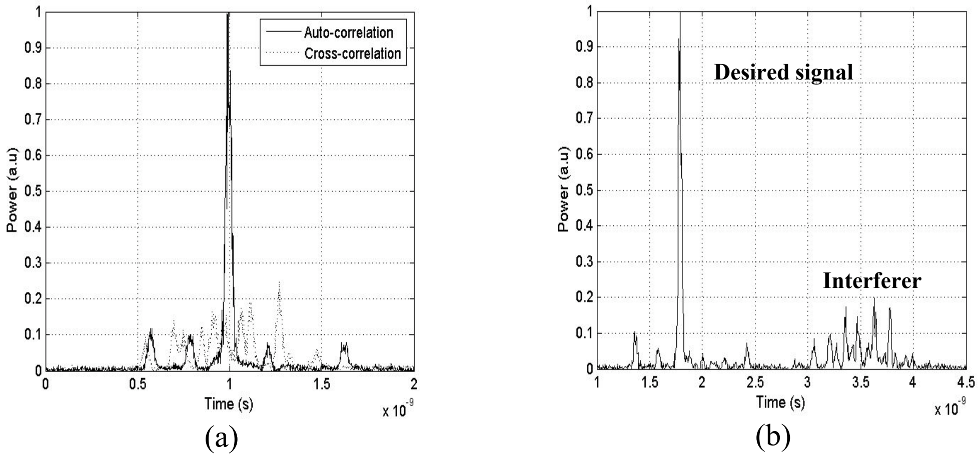

Figure 2. Measured auto and cross-correlation function: (a) Single-user configuration (without interferer), (b) Two-users configuration (in presence of one interferer).

In Fig. 2(b), the auto and cross-correlation functions, in presence of an interferer, are presented. In the asynchronous case, the interferer is delayed from the desired signal.

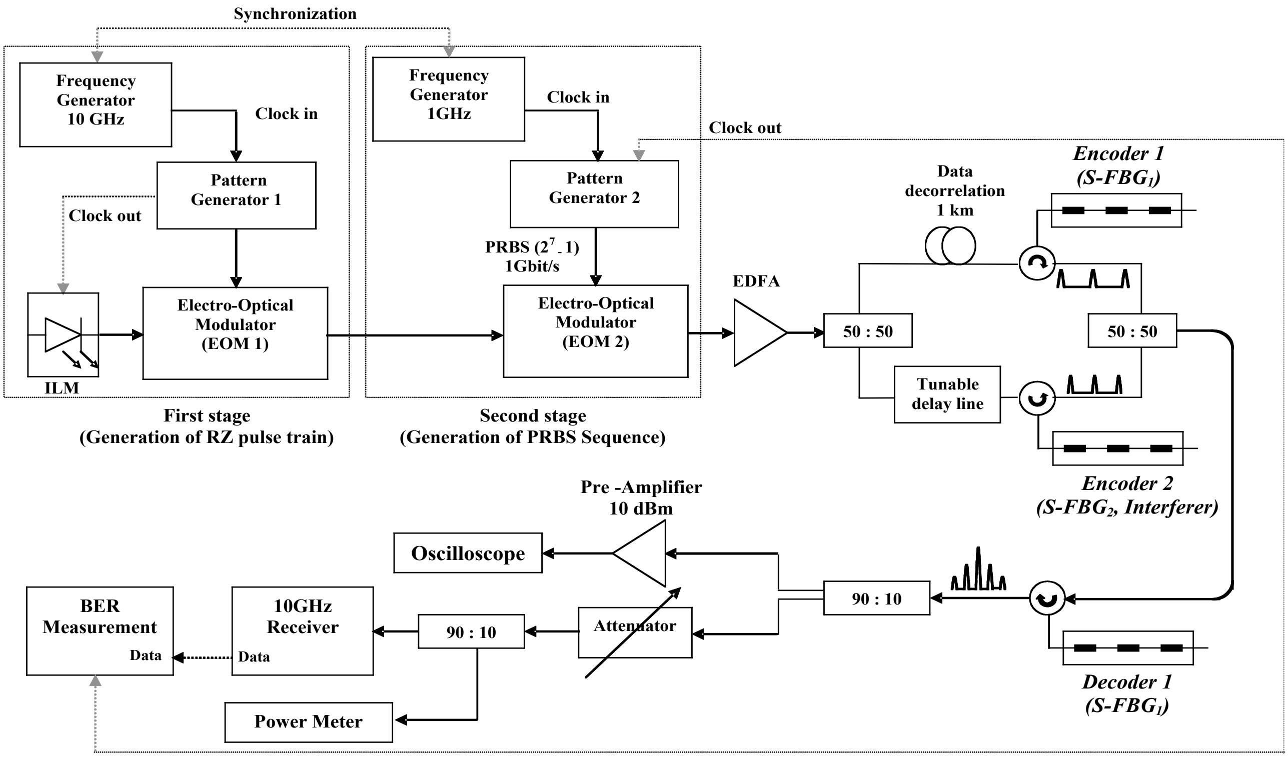

Figure 3. Experimental setup of BER measurement involving 2 multiplexed users.

A BER analysis has been performed with a 1 Gbps OCDMA setup, which takes into account the MAI effects (Multiple Access Interferences) from a second user. MAI effects and optical noise sources are both considered during this BER analysis.

Fig. 3 shows the experimental setup. It consists of a 1551 nm DFB laser with an Integrated eLectro-absorption Modulator (ILM). This system driven by a clock signal from a pattern generator allows the laser to operate in a pulse regime. The generated pulses full width at half maximum (FWHM) is 50ps. The pulse train is then RZ modulated by a first Electro-Optic Modulator (EOM1) at a data rate of 1 Gbps per user with a pulse ratio 1:10 (Fig. 4). The distance between two successive data pulses is 1000 ps, which allows the code chip pulses (9*50ps) to be placed easily between them. This is done to avoid pulse overlap during coding and decoding process.

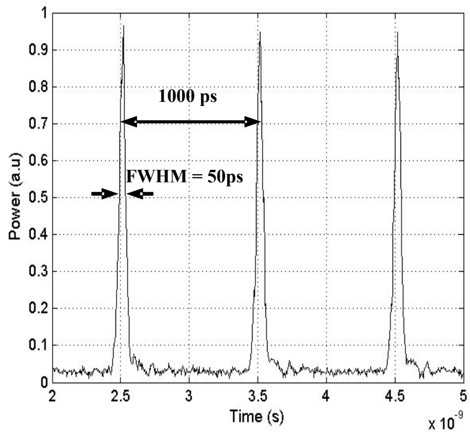

Figure 4. Waveform of RZ optical pulse train generated by the first stage at 1/10 repetition rate.

In the second stage, the 1 Gbps signal is modulated with a PRBS signal via a second Electro-Optic Modulator. The resulting pulse train is then amplified and encoded separately by S-FBG$_1$ and S-FBG$_2$ devices. To uncorrelate pulse trains from each encoder (which is the case in practical optical network), a time delay difference between the two encoders is set to be larger than the coherence time of the source, thus the two user signals can be considered as emitted from different light sources. The resulting signals are then superposed by a 3dB coupler and transmitted to the matched S-FGB$_1$ decoder. At the receiver, a variable attenuator is used to control the received optical power during the BER measurements. The bandwidth of the receiver is set to the chip rate.

The power budget of this transmission system is given in the following table 1 where the two users are activate, we note that the total reflected optical power of each encoder/decoder is around R =13%, which means that the insertion loss $L_{in} = -10 * Log(R)$ is about - 9 dB.

	Power [dBm]
After EOM 1	**-4.8**
After amplification (EDFA)	**10.13**
After Encoder 1 S-FBG1	**- 3.29**
After Encoder 2 (Interferer) S-FBG1	**-3**
Before Decoder (S-FBG 1)	**-5.16**
After Decoder (S-FBG 1)	**-11.16**

Table 1. Power budget of the transmission link

The total loss of the transmission link is about 21.3 dB, which is principally due to circulators, couplers and insertion loss of the encoders/decoders.

The high S-FBG reflection rate (13%) leads to suppress additional user pre-amplifiers and filters, usually required in all optical CDMA systems, to detect the encoded signals.

In the experimental setup, a set of a low pass filter, before measuring the BER, is not necessary thanks to the BGs filtering properties knowing that the encoder / decoder devices present a spectral bandwidth $\Delta\lambda$ = 1.6 nm which allows to reduce the spontaneous emission noise (ASE) induced by the optical channel.

The experimental BER measurements have been done using a 2^7-1 length PRBS sequence. Fig. 5 shows the results of these measurements. In the single user case, pulses pass through the encoder and are properly decoded. There is approximately less than 2 dB penalty at BER $=10^{-9}$ when compared to the back to back case. In the asynchronous two users case, both desired user (encoder C_1 by S-FBG$_1$) and the interferer user (encoder C_2 by S-FBG$_2$) send their pulses to the decoder (C_1 by reversed S-FBG$_1$). In this case, a BER $< 10^{-9}$ is achieved showing that the decoder correctly reject the pulses from the interferer.

In the synchronous two users scheme, the penalty versus the asynchronous case is about 2.5 dB for a BER~ 10^{-8} measurement. This shows that the impact of the multi user interference (MAI) on the system performances is higher than in the previous case.

The low power penalty between the single user and the two users asynchronous case (~ 2dB at BER~ 10^{-8}) is due to the fact that the auto-correlation function has weak sidelobes (~10 % of the maximum autocorrelation peak) which permit to select easily the correct peak and make the decision. In the next paragraph, we will discuss the reasons of this observed auto-correlation function form.

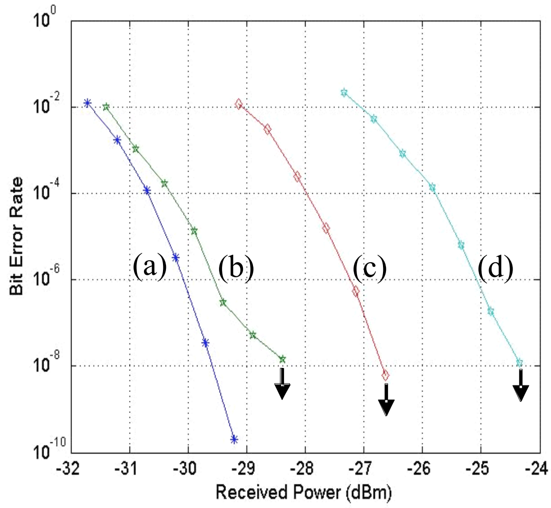

Figure 5. BER measurements vs. received optical power: (a) back to back (i.e. without encoder/decoder), (b) single user case, (c) two users asynchronous case and (d) two users synchronous case.

The performances of our OCDMA system are related to Fiber Bragg Grating technological limitations as well as to the used coherent pulsed source. First, we note that in Fig. 1, the pulse codes have not exactly the same optical power level, consequently, the auto-correlation function has the form presented in Fig. 2(a). It implies that the primary sidelobes of the PS code C_1 should have an optical power equal to 2/3 of the optical power of the main peak. This originates from BG wavelength mismatch inside an S-FBG encoder or decoder due to the fact that the BGs are written with different modulation indexes. Additionally, phase effects are observed as the devices behave as multipath interferometers, which lead to complex amplitude autocorrelation function instead of intensity one. These effects are under investigation and will be explained in the next future.

4. CONCLUSION

A 1 Gbps multiple user DS-OCDMA experimental setup using pulsed coherent source has been presented. Coding /Decoding is performed using Sampled Fiber Bragg Grating to generate the prime code sequences.

The design and the realization of the S-FBG components are performed to improve their mean reflected optical power. They permit to generate pulse chips with the same peak optical power level.

The 1Gbps DS-CDMA system successfully over come the multi-user interferences effects and achieved an error free operation with low system penalty levels in presence of interferer in both synchronous and asynchronous configurations as shown in the BER measurements. We have observed that the wavelength mismatch technological limitation during the UV S-FBG writing process, impact on the autocorrelation function of the system. Furthermore, the coherence of the system leads to interferometric perturbations, which influence the reconstruction of the data pulse train. Solutions to these problems are under investigation and will discussed in the next future.

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