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OCDMA low cost access network by using Bragg grating encoders/ decoders

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Abstract- **In an OCDMA system, prime sequences implementation is achieved by designing and realizing Sampled Fiber Bragg Gratings (S-FBG). Optimizing the characteristics of the S-FBGs allows to demonstrate low cost implementation for access network.**

Key words: Optical CDMA, Optical access demonstrator, Fibre Bragg Gratings

1- Introduction

Optical Code Division Multiple Access (OCDMA) is an attractive solution for low cost all optical access networks. Direct Sequence-OCDMA (DS-OCDMA) allows to each subscriber to use a specific codeword (or a code sequence) to modulate its data sequence. The resulting coded sequences of the various users, are superposed, transmitted via the optical amplified network and at least, detected by the suitable receivers.

Earlier, implementation of the optical codes has been achieved by using fiber splitters, optical delay lines and combiners [1]. Using the reflection properties of Sampled Fiber Bragg Gratings (S-FBG) to implement optical encoders/ decoders permits to solve the integration problems and accurate delay line requirement.

The efficiency of short SBG encoders/ decoders is demonstrated in this paper, since they present better performances than previous devices [2], and consequently allow to improve the power link budget leading to the suppression of user pre-amplifiers. In addition, the filter properties of SBG components reduce the noise induced by the optical amplified channel.

2- Optical Codes

The use of appropriate code sequences is the base of the code division multiple access techniques. In radiofrequency communication systems bipolar codes can easily be implemented. Their conception allows reducing the effects of multi-access interferences (MAI) since they present a good auto and crosscorrelation properties in the synchronous emission configurations. The use of these same bipolar codes in asynchronous conditions involves a crosscorrelation function deterioration inducing additional MAI.

For the optical CDMA application the use of bipolar sequences present more difficulties since the optical fiber does not conserve the signal phase. In the recent years, Fiber Bragg Gratings (FBG) have been used to implement bipolar spectral codes [ref]. These encoders/ decoders realizations need complex photo-inscription techniques and complex detection systems.

Despite of lower multiplexing capacity, sparsely coded sequences have been developed. The efficiency of these codes is independent on synchronization conditions since they present the same performances on synchronous or asynchronous emission configurations.

Using only unipolar pulses (also called chips), optical codes cannot be strictly orthogonal since the cross-correlations are not able to be suppressed. Nevertheless, a low crosscorrelation level is tolerated.

An optical code is defined by his length N (number of chips), his weight ω (number of "1" chips) and his multiplexing capacity N (number of maximum users).

To consider unipolar sequences as optical codes and control their crosscorrelation levels, some conditions have to be satisfied:

1- The autocorrelation function of a given code sequence have to be equal to his weight.
2- The autocorrelation function of a given code sequence must have a low correlation levels with his time shifted versions.
3- The crosscorrelation functions generated by to different code sequences have to be as low as possible.

To satisfy these conditions, the equations (1) and (2) highlights the unipolar sequence that can be used as optical codes:

For each unipolar sequence $x=(x_n)$:

$$\left|AC_{x,x}(m)\right| = \left|\sum_{n=0}^{M-1} x_n x_{n+1}\right| = \begin{cases} \omega & for \quad m=0 \\ \leq \lambda_a & for \quad 1 \leq m \leq L\text{-}1 \end{cases} \qquad (1)$$

For each $x=(x_n)$ and $y=(y_n)$

$$\left|CC_{x,y}(m)\right| = \left|\sum_{n=0}^{M-1} x_n y_{n+1}\right| \leq \lambda_c \quad for \quad 1 \leq m \leq L\text{-}1 \qquad (2)$$

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where λ_a and λ_c are, respectively, asynchronous autocorrelation and crosscorrelation levels.

Two important optical code families have been investigated for incoherent optical CDMA systems: Optical Orthogonal Codes (OOC) **[ref]** and Prime Sequences (PS) **[ref]**. Tables 1 and 2 give examples of OOC and PS codewords.

Table 1: Example of OOC

L	ω	N	Optical Orthogonal Codes
21	3	3	C_1(110001000000000000000)
21	3	3	C_2(101000000100000000000)
21	3	3	C_3(100100000001000000000)

Table 2: Example of PS

L	ω	N	Prime Sequences
21	3	3	C_1(100010001)
21	3	3	C_2(100100100)
21	3	3	C_3(100001010)

It was demonstrated that for the same auto and cross correlation constraints, PS exhibit better performances than OOC in term of multiplexing capacity for a given sequence length. One of the advantages of these codes includes simple encoders/ decoders design using fiber-optic delay lines or FBGs **[ref]**.

3- Sampled Fiber Bragg Grating Encoders/ Decoders Design and Realization

In our application, Prime Sequences (PS) C_1(100010001) and C_2(100100100) will be implemented respectively by SBG$_1$ and SBG$_2$ components since PS present a better multiplexing capacity than other optical codes [3-4].

By using the reflection properties of Fiber Bragg Gratings (FBG), optical pulses, separated by "0" chips are generated. The C_1 and C_2 prime code sequences are generated from $S\text{-}FBG_1(BG^1_1, BG^1_2, BG^1_3)$ and $S\text{-}FBG_2(BG^2_1, BG^2_2, BG^2_3)$ devices at a Bragg wavelength of 1550.95 nm. $BG^{i=1,2}_{j=1,2,3}$ represents the j^{th} 500 µm long Bragg grating corresponding to the j^{th} "1" pulse chip in the i^{th} codeword.

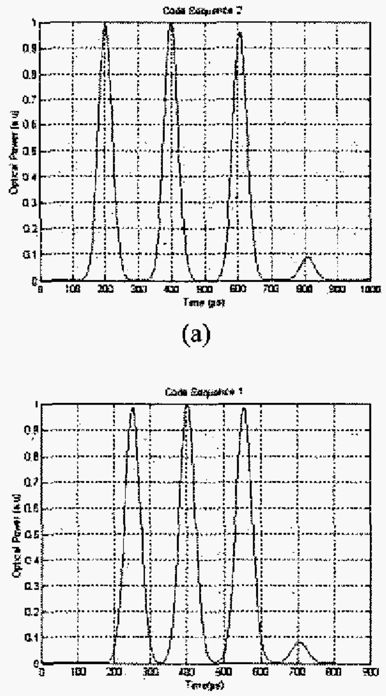
The optical fiber length between two consecutive BG^i_j and BG^i_{j+1} corresponds to the "0" chips of the i^{th} codeword.The reflectivity R_j of the $BG^i_{j=1,2,3}$ of the C_i encoder device is, respectively, 13% ($j=1$), 23% ($j=2$) and 33% ($j=3$). In the case of $S\text{-}FBG_1$ encoder, a *20.9 mm* fiber length separates two consecutive gratings, which corresponds to three times the "0" chip duration. For the $S\text{-}FBG_2$ encoder, a *15.0 mm* fiber length separates two consecutive gratings, which generates twice the "0" chip duration.

Table 3: Encoders / Decoders characteristics

	SBG_1	SBG_2
BG_1	$L_{BG1} = 500\mu$ $R = 13\%$	$L_{BG1} = 500\mu$ $R = 13\%$
$L_{BG1\text{-}BG2}$	22.5 *mm*	15 *mm*
BG_2	$L_{BG2} = 500\mu$ $R = 23\%$	$L_{BG2} = 500\mu$ $R = 23\%$
$L_{BG2\text{-}BG3}$	22.5 *mm*	15 *mm*
BG_3	$L_{BG3} = 500\mu$ $R = 33\%$	$L_{BG3} = 500\mu$ $R = 33\%$

Table 1 recapitulates the different parameters of the SBGs encoders/ decoders.

To generate codewords composed by pulses with the same level, each sampled grating is designed to present a different reflection rate, which compensates the incident wave attenuation during its propagation through the S-FBG device. A simulation of the reflected code sequences C_1 and C_2 generated by S-FBG$_1$ and S-FBG$_2$ in which a *50 ps* full-width at half-maximum (FWHM) pulse is launched, is displayed in Fig.1 (a-b).



(a)

(b)

Fig 1: Simulation of Prime Sequences
(a):C1(100010001)
(b):C2100100100)

Encoders/ decoders technological realization is achieved by photo-inscription of in-fiber short Bragg gratings by using the phase mask method **[ref]**. To accurately control the length between two successive gratings, the fiber is mounted on a piezo translation stage with a computer controlled interferometric nanometer rule. The accuracy of the BG positioning is in nm range.

4- Experimental Multiplexing Set Up

The experimental set up consists of a *1550.95 nm* DFB laser with an Integrated eLectro-absorption Modulator (ILM). This system driven by a clock signal from a sequence generator (SG) allows the laser to operate in a pulse regime. The resulting full-width at half-maximum (FWHM) of the generated pulses is *50 ps*.

The pulse train is then RZ modulated by an electro-optic modulator (EOM) at a data rate of *2 Gbit/s* per user with a pulse ratio 1:10.

A first back to back all optical CDMA demonstrator is displayed on Figure 2. The realized encoder/ decoder devices have been integrated in this first experimental set up.

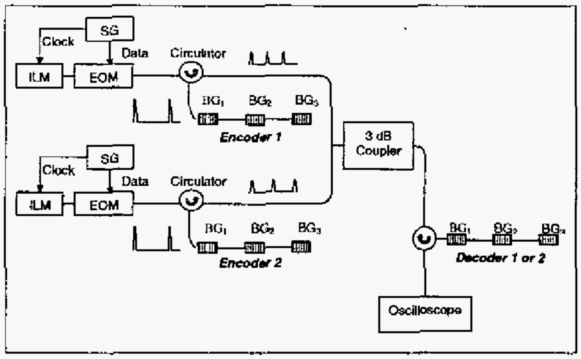
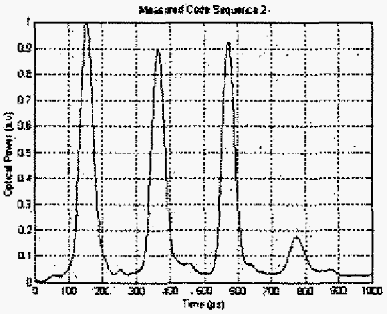
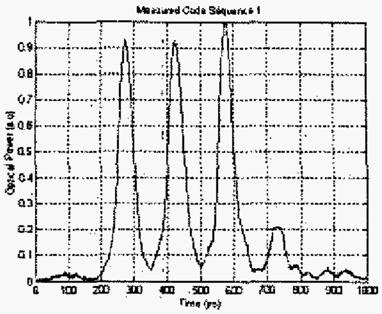


Fig.2: Back to back all-optical CDMA communication system

For each user, an S-FBG encoder generates the appropriate code sequence. Figure 3 (a-b) shows the generated of codeword $C_1(100010001)$ and $C_2(100100100)$ associated to the two users.



(a)



(b)

Fig 3: Measured Prime Sequences
(a):C1(100010001)
(b):C2100100100)

The measured code sequences shown on this figure are in a good agreement with the simulated codewords. The FWHM of the pulses is *50 ps* and each two pulses are separated by a time duration of three "0" chips equal to *150 ps*.

This first demonstrator allows to involve the autocorrelation function (Figure 4-a) and the effects of the crosscorrelation function (Figure 4-b) obtained by using, respectively, a matched and a mismatched decoder in a presence of an interferer (a second user)

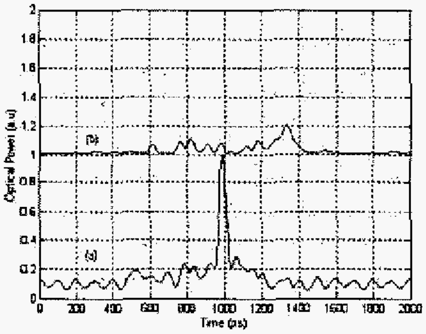


Fig.4: Back to Back configuration
(a): auto-correlation function
(b): cross-correlation function

The obtained auto and cross correlation functions demonstrate that a matched decoding permit to recover the useful signal associated to the desired user when a no adapted decoding spread the signal power and do not allow to rebuilt the data sequence.

In a second demonstrator, the encoder/ decoder devices have been integrated in an OCDMA optical amplified system demonstrator displayed on Figure 5.

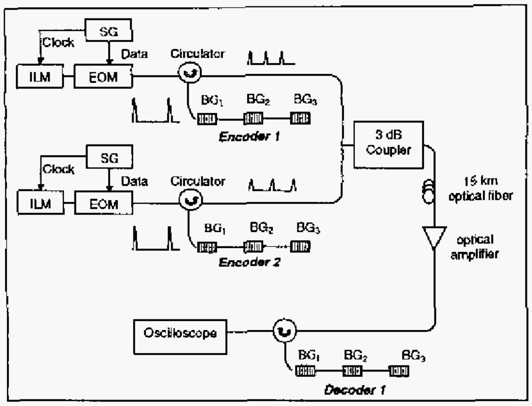


Fig.5: OCDMA optical amplified system demonstrator.

In this two user demonstrator, the coded signals obtained by the SBG devices are superposed by a 3 dB coupler, transmitted through *15km* optical fiber, amplified and decoded by a matched decoder device.

To estimate the performances of the proposed system, we have measured the auto and cross-correlation functions of the code sequences. Figure 6 shows the autocorrelation associated to the first user before and after the *15 km* optical fiber. The autocorrelation peak corresponds to a matched decoding and its FWHM is *52 ps* due to the chromatic dispersion. This effect has no influence on the decoder performances.

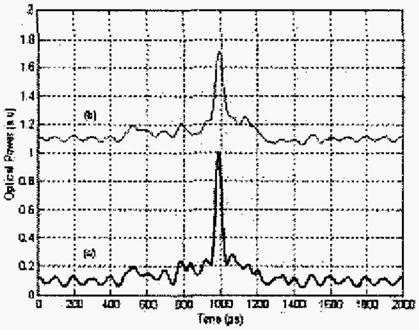


Fig.6: Auto -correlation functions
(a): before 15 km optical amplified channel
(b): after 15 km optical amplified channel

The high SBG reflection rate leads to suppress the user pre-amplifiers employed to detect the decoded signals. The SBG's filtering properties allows to reduce the noise induced by the optical amplified channel. This demonstrates the efficiency of our OCDMA low cost communication system.

5 Conclusion

The realization of a low cost all optical access network by using DS-OCDMA multiplexing technique and SBG devices as encoders/ decoders has been reported.
Design and the realization of SBG components are performed to improve their mean reflected optical power. Furthermore, they permit to generate pulse chips with the same peak optical power level.
At least, the multiplexing of two encoded signals through a typical *15 km* access network length is demonstrated without additional optical filter and user pre-amplifier.

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