ECOC'99 25th European Conference on Optical Communications, vol. I, pp. 190-191

Experimental Demonstration of Optical Fast Frequency Hopping-CDMA Communications

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Abstract: We demonstrate an all-fiber fast optical frequency-hop code division multiple access (FFH-CDMA) for high bandwidth communications. Transmission rates of up to 1.6 Gb/s per user were achieved with an 8-wavelength multiple Bragg grating written in 8 cm of fiber.

Introduction

Code division multiple access (CDMA) is a highly flexible multiple access protocol, however, significant signal bandwidth expansion is required. Given the Terahertz pass band of optical fiber, the frequency spreading of the CDMA signal is no impediment, *provided it can be accomplished optically*. Among wide variants of optical CDMA techniques, only a spectral encoding based approach [1] has penetrated the market.

CDMA techniques based on in-fiber signal processing are the most promising due to the complexity and coupling loss reduction. In [2-4], we proposed fast frequency hopped CDMA (FFH-CDMA) based on all-fiber multiple Bragg gratings (MBGs). Theoretical analysis and numerical simulation showed that the system could accommodate a large number of users at bit rates exceeding the 1 Gbit/sec [2,4]. In this paper, we report an experimental demonstration of the optical FFH-CDMA encoding/decoding system, including a single receiver and two transmitters at bit rates varying from 100 Mb/s to 1.6 Gb/s.

Design of the Encoding/Decoding Devices

In optical FFH-CDMA each information bit from a given user is encoded onto a time/frequency code sequence (or hop-pattern) as presented in matrix form in Figure 1a [6]. The MBG presented in Figure 1b imprints the hop-pattern onto data-modulated, wideband, short-duration pulses generating a fast frequency-hopping signal.

Note that the decoder and encoder are ***identical*** MBGs. As seen in Figure 1b, encoding is achieved for a signal entering/exiting from the left, *i.e.* λ_5 seen first. Decoding occurs when the encoded signal enters/exits from the right. Three important specifications that all gratings should have to correctly perform encoding/decoding: 1) identical reflectivity peaks, in height and width, 2) identical wavelength values and wavelength spacing and 3) identical physical spacing between gratings.

We wrote the multiple Bragg gratings using the Sagnac type interferometric technique described in [5]. We designed a complementary procedure, not described here, to achieve a plurality of identical fiber MBGs with highly efficient reproducibility.

Figure 1 a) hop patterns, E1 (respectively D1) refers to the time/frequency slots used by the encoder 1 (respectively decoder 1) b) MBGs physical parameters.

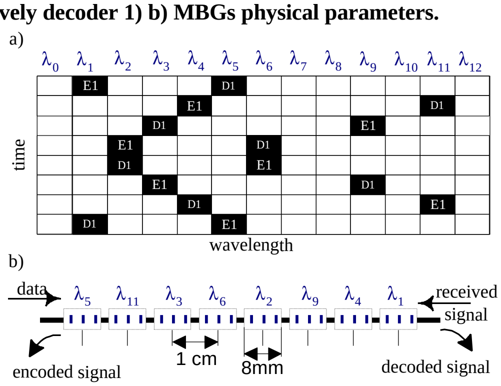


Figure 2 a) Reflectivity, and b) group delay of the encoder (solid line) and the decoder (dashed line).

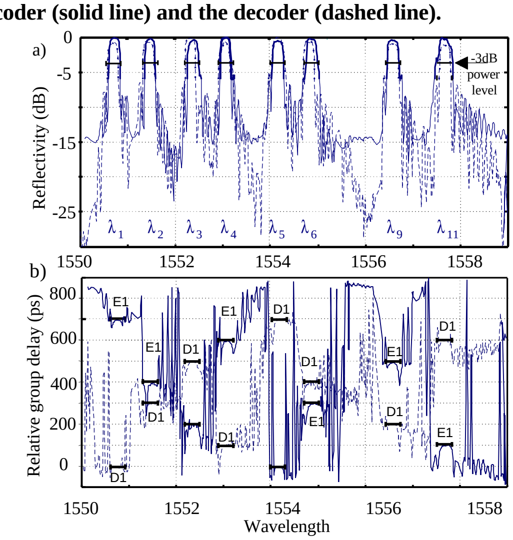


Figure 3 Reflectivity (a) and group delay (b) for a back-to-back, correctly matched encoder/decoder pair (solid line) and a mismatched pair (dashed lines).

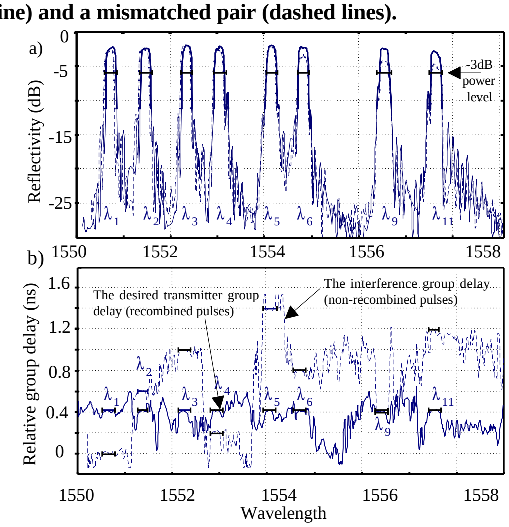
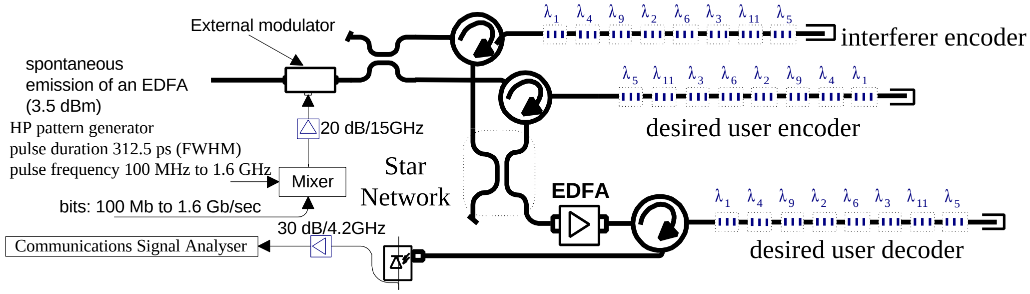


Figure 4 Experimental setup of an FFH-CDMA communications system including two transmitters and one receiver.



In this paper we present results for three identical MBGs of 8 gratings written to the hop pattern of Figure 1a, with the physical parameters of Figure 1b. The reflectivity and group delay of two of these MBGs is shown in Figure 2, as measured with wavelength steps of 0.01 nm. No fusion is made between gratings. All the MBGs met the previously mentioned specifications: 1) a maximum peak variation of 1 dB; 2) wavelength spacing in multiples of 0.8 nm, with precision <0.15 nm in the same fiber; variation of absolute wavelength between encoder and decoder is <0.08 nm, and 3) physical spacing is 1 cm, with a precision <10 µm, *i.e.* 100 ps hopping time.

The reflectivity peaks have mean FWHM < 0.24 nm (see bars across reflectivity peaks in Figure 2a and corresponding bars in group delay). Examining the group delay during the FWHM intervals shows that the MBGs achieve the time-frequency pattern of Figure 1.

Decoding is successful only when the delays introduced by the encoder for each frequency element have a complementary delay from the decoder leading to a single cumulative delay for all elements (see the 0.4 ns line in group delay of Figure 3 for back-to-back correctly matched MBG pairs). As seen in the dashed line of Figure 3b, when the encoder and decoder are mismatched (as is the case for interfering signals) delays are different for each frequency element and there will be no autocorrelation peak.

Two Transmitter/Single Receiver Setup

As illustrated in Figure 4, the spontaneous emission of an EDFA (erbium doped fiber amplifier) and an external modulator are used to generate the data-modulated, wideband, non-coherent, short-duration pulses. These pulses are fed to two MBGs through distinct circulators. The reflected signals are summed and amplified with an EDFA and fed to a decoder. The transmitted and received pulses, for 100 Mb/s, are superposed in Figure 5.

Figure 5 Decoder output for different scenarios.

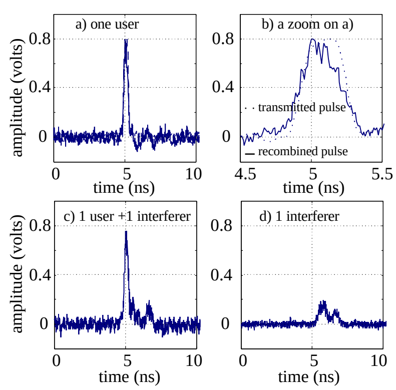


Figure 5a shows a strong autocorrelation peak with no appreciable distortion of the pulse seen in the zoomed plot (Figure 5b). The autocorrelation peak is clear also in Figure 5c when an interferer is present (Figure 5d shows interferer only and no signal). In Figure 6 an autocorrelation peak is clearly discernable for bit rates from up to 1.6 Gb/s. Thus the technique is effective even with pulses much longer than the gratings physical spacing.

Conclusion

We presented an experimental demonstration of an optical implementation of FFH-CDMA. We produced MBGs within tight tolerances to meet the stringent requirements of the FFH-CDMA for high bit rates. Transmission of bit rates of up to 1.6 Gb/s were achieved with an 8-wavelength multiple Bragg grating written in 8 cm of fiber.

References

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Figure 6 One desired transmitter and one interferer; data rates varying from 0.2 to 1.6 Gb/s.