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AN OCDMA RECEIVER INCORPORATING A HOLEY FIBRE NONLINEAR THRESHOLDER

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Abstract: We demonstrate the use of an optical thresholder based on a short length of holey fibre to achieve enhanced code recognition quality in a 255-chip, 320Gchip/s superstructured fibre Bragg grating based OCDMA code:decode system. Use of the device allows error free, penalty free operation to be obtained.

Introduction

There is a growing interest in the development of all-optical code generation and recognition techniques for Optical Code Division Multiple Access (OCDMA) applications. Optical matched filtering using pairs of optical filters with conjugate impulse response functions provides perhaps the most convenient means to generate/recognise optical code sequences. Recently, Superstructured Fibre Bragg Grating (SSFBG) technology has emerged as a means of fabricating filters with suitably precise and complex impulse response functions for generating/recognizing both amplitude and phase encoded sequences /1/. In SSFBG based OCDMA schemes the reflection of a short pulse from one SSFBG (the encoder) results in the generation of a code sequence. This code can then be recognised (at a particular receiver) by subsequent reflection from a second SSFBG (the decoder) that has a spatially reversed refractive index profile relative to that of the encoder. This process results in the generation of a pulse form in the time domain with a temporal structure corresponding to the autocorrelation function of the code. Simple intensity discrimination techniques can then be used to detect code recognition provided that only code sequences are used within the system that have: (a) a distinctive autocorrelation characteristic comprising a short, relatively intense pulsed feature, (which is in general unavoidably accompanied by an extended low level pedestal), and (b) mutually low cross correlation characteristics. Whilst good operation of such 'linear' optical systems can be achieved, nonlinear optical techniques that can eliminate the extended low-level pedestal associated with the matched filtering process are desirable, since removal of this pedestal enhances the contrast of the pattern recognition signature. This is particularly important within OCDMA systems since a particular coded signal generally needs to be recognised in the presence of other orthogonally coded signals, each of which gives also rise to low level pedestal signals when filtered, and which can interfere with the decoded signal.

The use of fast, fibre based nonlinear thresholding devices within OCDMA receivers has been previously demonstrated, and these devices were based on either the filtering of spectrally broadened signal components generated through Kerr nonlinearity /2/, or soliton effects in a nonlinear optical loop mirror /3/. Both of these devices employed conventional silica fibres and were impractical since the relatively low nonlinearity of these fibre types means that long fibre lengths (several km) are required.

Holey fibre (HF) technology however now allows the fabrication of fibres with very tightly confined modes, and thus very high optical nonlinearities per unit length. Indeed, a silica holey fibre can have a nonlinearity 10~100 times that of a conventional silica fibre. Nonlinear devices based on HF can thus in principle be 10-100 times shorter than similar devices based on conventional fibre technology, offering a route to the development of truly practical, ultrafast fibre based nonlinear devices.

In this paper we present for the first time experimental results concerning the use of a HF nonlinear thresholding device within an OCDMA receiver. Using a short (8.7m) length of HF we achieve enhanced code recognition quality in a 255-chip, 320Gchip/s superstructured fibre Bragg grating (SSFBG) based OCDMA code:decode system. Error-free, penalty-free system performance is obtained and the ~3dB power penalty observed for pure matched filtering alone is eliminated.

Experimental setup and results

Our experimental set up is shown in Fig. 1. 2.5ps pulses at 10GHz are first generated using a regeneratively mode locked erbium fibre ring laser (EFRL) operating at 1553nm. These are then modulated/gated using a 10GHz external modulator to obtain a 1.25 Gbit/s data stream.

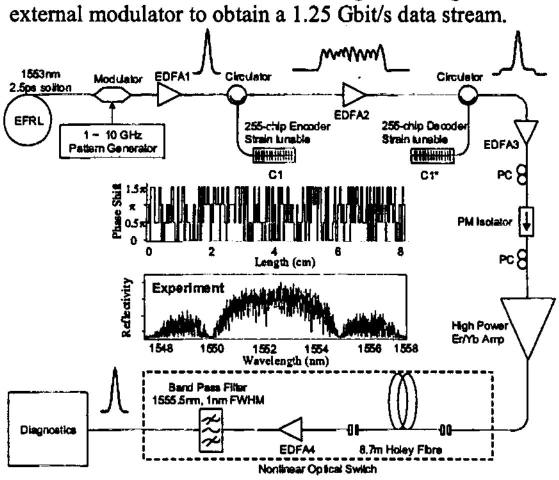

Fig. 1: Experimental set up. Inset: 4-level phase coding scheme and grating reflectivity profile. (Note that the characteristics and properties of the gratings are more fully described in Ref. /1/).

The 1.25 Gbit/s, short pulse data stream was then launched onto an SSFBG encoder (C1) containing 255-chip, 320Gchip/s quaternary phase code sequence coding information. The chip duration was thus 3.2ps and the coded data pulses had a total duration of ~800ps. The particular code used is a member of the Family $\mathcal{A}$ sequences that have been applied within wireless CDMA communications (see inset Fig. 1). The coded signal was then fed directly to the associated matched decoder grating C1*. Since the encoder and decoder gratings are matched then, as previously explained, the decoder output should exhibit a short, chip length long autocorrelation spike centered on a relatively broad, (1.6ns) pedestal /4/. The nonlinear HF based optical thresholder was located after the decoder grating and was preceded by a fibre amplifier.

An SEM of the transverse profile of the highly nonlinear HF is shown inset in Fig. 2a. The core diameter is ~2.0μm and the outer diameter of this fibre is 125μm. Due to the large air holes and small core size the fibre is both highly nonlinear and highly birefringent (measured beat length 0.43mm). The nonlinear coefficient γ of the guided mode in this fibre was measured to be γ=31W^{-1} ·km^{-1}, from which we derive an estimate of A_{eff}=2.93(+/-0.3)μm^2 for its effective area. This nonlinearity is ~20 times higher than that of a conventional dispersion shifted fibre.

Self-phase modulation (SPM) accompanied by Raman scattering in the highly nonlinear HF due to the intense autocorrelation spike results in (asymmetric) spectral broadening of correctly decoded bits (see Fig. 2b). A self-switched signal with a transfer characteristic suitable for intensity thresholding (see Fig. 2c) was obtained by filtering the resulting spectrally broadened signal with a narrowband dielectric filter that had its center-wavelength offset by (+2.5nm) relative to the peak wavelength of the incident signal. The 3dB bandwidth of the filter was 1nm. This value was chosen to ensure that the switched output pulses had roughly the same temporal width as the 2.5ps input pulses (see Fig. 3a).

In order to assess the impact of using the HF switch as an optical thresholder we first measured the eye diagrams. The improved pattern recognition contrast is clearly evident on a 20ps timescale by comparing the eyes and background noise levels in Fig. 3b, and on a ps timescale in Fig. 3a. The low-level pedestal obtained with simple matched filtering is almost completely eliminated. To quantify the benefits of the pedestal rejection from a system perspective BER measurements were performed as shown in Fig. 3c. The observed ~3dB power penalty associated with matched filtering alone is totally eliminated. It should be mentioned that since the fibre has anomalous dispersion (D~100 ps/nm-km) the filtering process results in additional noise on the 'one' bits (see Fig. 3b) due to coherence degradation /4/. However, for this particular application this does not appear to lead to any penalty. Indeed, a ~1dB penalty improvement relative to the laser back-to-back case was obtained due to clean up of residual radiation in the zero bit slots due to the poor (~-14dB) extinction ratio of the external data modulator (see Fig. 3b: back to back trace).

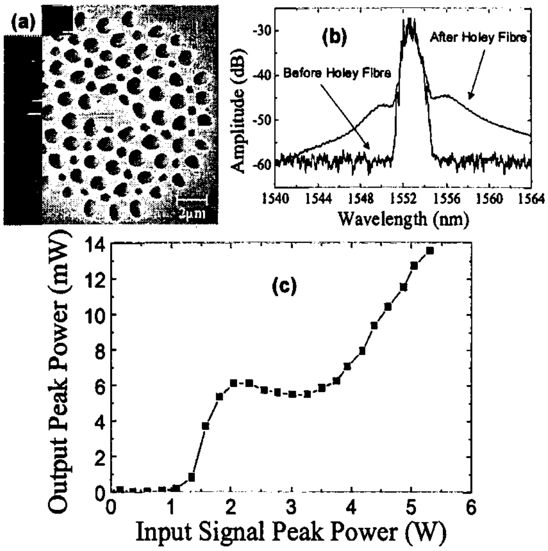

Fig. 2: (a) SEM of the transverse profile of the HF used in this experiment. (b) Signal spectrum both before and after the HF. (c) Power transmission characteristic of the HF switch as a function of the input peak power.

Conclusion

We have experimentally demonstrated that an optical switch based on a short length of HF can be readily used to enhance code recognition contrast in a SSFBG based OCDMA code:decode system. This experiment represents just one example of a practical application of a HF based nonlinear device. We consider that this will be the first of many such demonstrations and that nonlinear HF devices will ultimately prove of great practical relevance for future communication systems.

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References

/1/ P. C. Teh et al. *Proc. OFC'2001*, PD37 (2001).
/2/ H. P. Sardesai et al. *Electron. Lett.*, v.33 (1997) pp.610-611.
/3/ J. H. Lee et al. *Photon. Tech. Lett.*, v.13 (2001) pp.529-531.
/4/ M. Nakazawa et al. *Optics Lett.*, v.24 (1999) pp.318-320.

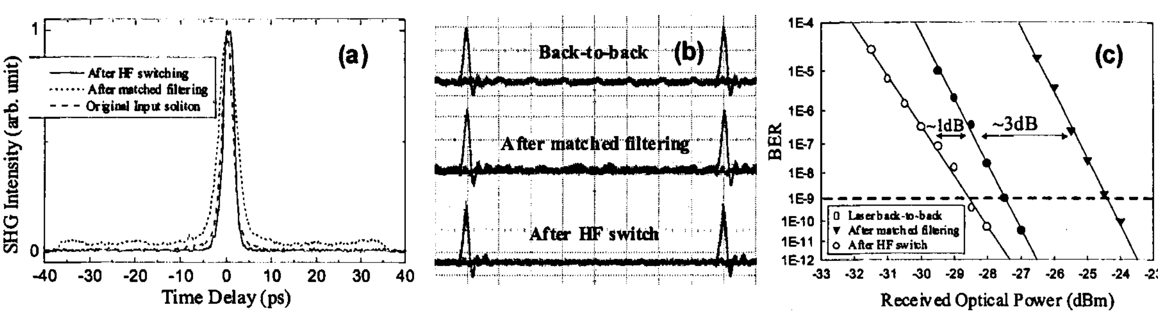

Fig. 3: (a) SHG autocorrelation traces, (b) Eye diagrams and (c) BER versus received optical power, for the 1.25Gbit/s OCDMA system.