Customized FBG based photonic superstructure for UWB signal generation applications

Vanessa MORENO (2), Jose MORA (1), David BARRERA (1), Miguel A. MURIEL (2), Jose CAPMANY (1)

1. ITEAM Research Institute, Universitat Politècnica de València, C/ Camino de Vera s/n, Valencia 46022, Spain
2. Department of Photonics Technology and Bioengineering, ETSIT, Universidad Politécnica de Madrid (UPM), Av.Complutense 30, Madrid 28040, Spain

Contact name: Jose Mora (jmalmer@iteam.upv.es).

ABSTRACT:

This paper proposes and experimentally demonstrates a compact and scalable approach for high-order UWB pulses based on phase-to-intensity conversion by means of a FBG photonic superstructure. In this scheme, we have designed a customized FBG assemblage that permits lineal combination of UWB low-order derivatives to generate high order pulse generation. Experimental results are depicted from the preliminary design of the array. The generated pulses are presented in both time and frequency domain, revealing a proper fit in terms of the FCC settled mask and hence, optimal efficiency percentages.

Key words: Photonic superstructure, High Order Pulses, Optical pulses generation

1. - Introduction

The concept of employing Microwave Photonics (MWP) and Ultrawideband (UWB) operating jointly within the optical domain [1-2] has emerged as a practical solution that provides valuable features such as: tunability, light weight, low loss, small size capability, high data rates and spectrum cohabitation capacity [3]. At the same time, that improves drastically the usually constrained UWB coverage area range [4]. Parallel to this, fiber bragg gratings (FBGs) have been widely used and have rapidly evolved in fiber optic-based signal applications due to their excellent properties in terms of simplicity, polarization independence, low cost and seamless integration in fiber optics systems. Moreover, FBGs result immune to electromagnetic interference (EMI), chemically inert and spark free [5].

In this context, various fiber based concepts have been approached for UWB distribution [6] and generation purposes [7]. Among the most relevant generation schemes, we can find dispersion-induced frequency-to-time mapping [8], microwave photonic filtering [9], SOA nonlinear operation [10] and phase-to-intensity (PM-IM) conversion [11]. However, in all these proposals, there is at some point a trade-off between flexibility and optimization. In this way, there is an efficient technique that has recently been proposed to obtain UWB high order signals that relies on the merge of various low order UWB pulses, such as monocycles and doublets to generate higher order ones, as triplets or quadruplets [12-13]. Although, these schemes have proved to be valid, they hold some deficiencies such as lack of flexibility, low reconfiguration and finally, limited integration features.

In this work, a flexible UWB high order pulses generator based on a Fiber Bragg Gratings (FBGs) superstructure has been proposed and experimentally demonstrated. The remains of this paper go on as follows: In section 2, we describe the principle of operation of the structure, the details behind

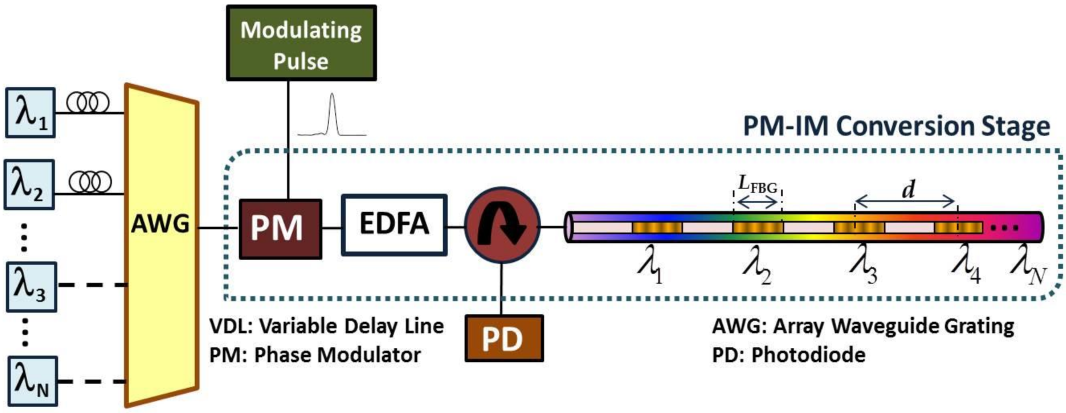

Fig. 1: Experimental setup for the generation of high-order pulses generation FBGs based on a FBG photonic superstructure.

the design of the photonic superstructure as the key component and then the generation architecture itself, which relies on the combination of a phase modulator with the abovementioned customized FBG array for a simultaneous process of PM-IM conversion [14] and pulse shaping. In section 3, time and frequency domain measurements corresponding to an obtained UWB triplet and its low derivative basis are exposed and such experimental results are discussed. Finally, conclusions will be addressed in section 4.

2. - Principle of Operation

Figure 1 illustrates a generation architecture sustained on a customized photonic superstructure based on four concatenated FBGs. The concept of this experiment relies on the flexibility feature depicted by the system, since each FBG permits to operate at different working points along its optical transfer function providing different pulse generation possibilities. In the experimental scheme, the optical input signal from a set of "N" sources is phase modulated by a Gaussian pulse train that can be expressed in the form of:

$$p(t) = \sum_{k=-\infty}^{+\infty} A_k \exp\left[-\left(\frac{t-k\tau}{\delta_\tau} \right)^2 \right] \qquad (1)$$

Where τ stands for the separation between adjacent pulses and $\delta\tau$ for their width. This train holds a pulse sequence with a fixed pattern of one "1" and sixty three "0" (total 64 bits) at a 12.5 Gb/s bit rate. The Phase Modulator (PM) employed has an insertion loss of 3.5 dB and a 3dB-bandwidth of 20 GHz. Once phase modulated, the normalized optical can be represented by:

$$E_{PM}(t) = \exp[j\omega_c t + j\beta_{PM} \cdot p(t)] \qquad (2)$$

In this case, ω_c is the angular frequency and β_{PM} the phase modulation index. This obtained pulse is then amplified by an Erbium Doped Fiber Amplifier (EDFA) and introduced to the FBG superstructure through an optical circulator. It is during this stage where the desired PM-IM conversion in function of the selected optical wavelength takes place. The basic conversion process can be analyzed by taking into consideration one FBG as an ideal frequency discriminator. Since, It is known [15] that the response of a frequency discriminator is given by $H_{out}(\omega) = K(\omega\text{-}\omega_0)$, where K denotes the slope of the frequency response and ω_0 the angular frequency at which $H_{out}(\omega) \approx 0$. Therefore, supported on the convolution property [16], the phase modulated light after passing by this optical filtering stage holds a response in the frequency domain of:

$$E_{out}(\omega) = \left[K(\omega - \omega_0) \right] E_{PM}(\omega) \qquad (3)$$

Where $E_{PM}(\omega)$ represents the Fourier transform of $E_{PM}(t)$. When analyzing this output within the time domain by means of the inverse Fourier transform (IFT), we observe that corresponds to:

$$E_{out}(t) = \left[K(\omega_c - \omega_0) + K\beta_{PM}\, p'(t) \right] E_{PM}(t) \qquad (4)$$

Here, $p'(t)$ exemplifies a Gaussian pulse first derivative and hence, an UWB monocycle. It must be mentioned that even after the photo detection step incorporated for time analysis purposes, the monocycle pulse remains as part of the detected signal.

In this solution, as it was already mentioned the key element is comprised by the FBG based pulse shaping assemblage constituted by 4 FBGs designed with an apodized profile considering a precise separation "*d*" and length "*l*" in order to maximize the PM-IM conversion process. Here, if the optical carrier is located at the opposite slope of the FBG reflection spectrum, the output will hold a π phase difference. Therefore, we have translated this into the possibility of generating complementary waveforms by means of two different FBGs within the array. Among other beneficial features, if the optical carrier is located at the quadrature slopes of the reflected spectrum, a doublet pulse (or a Gaussian second derivative) is accomplished.

In terms of fabrication, the gratings hold a specific apodized profile to reduce the secondary lobes of their spectrum in order to minimize the crosstalk between channels. For this solution, the FBG inscription has been performed employing an Argon ion frequency-doubled laser at a wavelength of 244 nm. This procedure is based on the use of an uniform phase mask combined with a precise relative movement between the phase mask and the optical fiber [17]. Such technique permits apodization of the refractive index modulation along the optical fiber in order to tune the FBGs optical spectra. The use of a boron co-doped optical fiber increases the photosensitivity and a Kaiser apodization is employed in these gratings in order to obtain the desired spectral response. The reflectivity of the FBGs obtained through this process varies between 82% and 90%.

For further specific design parameters, we have considered that quality of the reflected spectrum and distance between each wavelength component will determine the quality of the high-order pulse to be produced. Firstly, the separation was analysed. This characteristic was tagged as "*d*" and was tuned to be around 8 mm since the optical delay, τ, between optical taps holds a direct relationship with such factor by means of the expression:

$$\Delta\tau = 2n_0 d / c \tag{5}$$

Where, $\Delta\tau$ was determined to be close to 77 ps, which corresponds to a Free Spectral Range ($FSR = 1/\tau$) of approximately 12.9 GHz. Note that the FSR/2 around 6.45 GHz matches with the central frequency of the expected UWB spectral band. Apart from the optical delay between adjacent samples, spectra of each FBG are spectrally approximately equispaced. The FBGs are centred at the wavelengths λ_{Bragg1}=1549.808 nm, λ_{Bragg2}=1550.712 nm, λ_{Bragg3}=1551.656 nm and λ_{Bragg4}=1552.610 nm. Finally, we evaluate the optical filter in function of the length. Power reflected spectrums of various FBGs which were manufactured in our lab facilities specifically for this experiment were analysed. Apart from verifying the phase-to-intensity conversion, we corroborated the accuracy of the spectral distance and shape between the generated waveforms as well as the absence of undesired pulse broadening. Fig. 2 reveals these preliminary tests. In this context, the length of the FBG is a flexible parameter. For this scheme, a 7 mm length (*l*) is considered the most optimal value for mask compliance purposes.

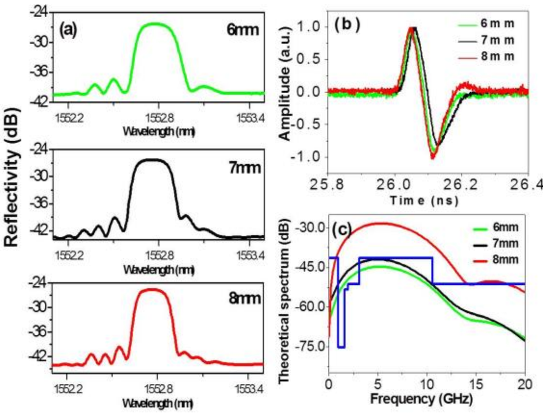

Fig. 2: Experimental (a) optical power spectral density, (b) generated monocycles and (b) corresponding theoretical electrical spectra for FBGs with different lengths of 6, 7 y 8 mm.

3. - Results

To demonstrate and validate the capabilities for generation of the proposed set up, different signals were produced and analyzed. The main property featured by the superstructure is its capacity of generating UWB high order pulses by combining lower-order ones. In spite the fact that monocycle and doublet pulses are widely used due to their simplicity, high-order derivatives of Gaussian pulses are more suitable candidates for UWB systems in terms of spectral efficiency and FCC mask compliance.

To validate the before mentioned concept, in this set up a UWB triplet is accomplished by means of the lineal sum of two inverted doublet pulses. In this implementation, two lasers were employed with an optical power value of 5.5 dBm each one. Activation of such optical sources is proportional to the number of lower order pulses to be reconfigured in the outcome signal. Wavelength values to be employed are directly related with the base UWB waveforms to be employed and hence the PM-IM conversion working point. For this optical scheme, these parameters were set up at 1551.614 nm and 1552.557 nm, corresponding to a positive and a negative doublet within the third and fourth grating respectively. The generated UWB triplet depicts a fractional bandwidth of 99.8 % with a spectral efficiency of 65 % in the 3.1-10.6 GHz band. The temporal and frequency response of the obtained triplet pulse and its lower base derivatives are displayed in Fig. 3(a), 3(b), 3(c) and Fig. 3(d), respectively.

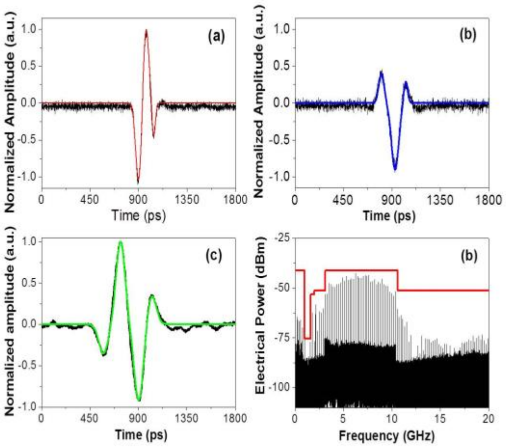

Fig. 3: Experimental (a) generated positive doublet (b) generated negative doublet (c) generated UWB triplet pulse and (d) corresponding electrical spectra

4. - Conclusions

In this letter, we have proposed and demonstrated a flexible high-order UWB pulse generation system based on a photonic FBG superstructure. The key point is to take advantage of the benefits provided by the PM-IM conversion process that takes place in the designed optical component and generate high-order pulses, through the combination of various low-order Gaussian derivatives with their corresponding inverted polarity waveforms. The main component in this scheme is represented by the photonic superstructure designed in our lab facilities, this concatenated FBGs arrays implies proper selection of key parameters such as the separation, the length and a specific apodized profile to maximize the PM-IM conversion process and minimize the crosstalk between adjacent FBGs. Generation feasibility was demonstrated by creating an UWB triplet pulse with a spectral efficiency around 65 % by means of the sum of complementary doublets of 23 % efficiency each.

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