Optical Time-Division Multiplexing (OTDM) Using Soliton Pulses in a Terahertz Optical Asymmetric Demultiplexer (TOAD)

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Abstract: The performance of a Terahertz Optical Asymmetric Demultiplexer (TOAD) operating with an ordinary fiber and with a DDF and DIF (Dispersion Decreasing and Increasing Fiber) configurations, for three length of fiber ($\xi = \pi/2$, 2π and 5π) and using soliton and quasi-soliton laser profile for the control pulse, was studied. We also did simulations with the TOAD operating with DDF in four different profiles: Hyperbolic, exponential, linear and Gaussian. Operating the TOAD using a DDF fiber one can say that the control power necessary to demultiplex the signal pulse is always lower compared with the TOAD with the normal telecommunication fiber. For all the profiles the increase of the length of the fiber also decrease the pump power of the three first peaks for the soliton and quasi-soliton regime.

1. Introduction

The nonlinear optical loop mirror[1] (NOLM) and the nonlinear amplifying loop mirror[2] (NALM) have been shown to possess optical switching properties[3] when they are unbalanced by an asymmetric coupler and by an asymmetrically placed gain element, respectively. The NOLM has been one of the most successful devices for demonstrating a range of all optical processing functions including soliton switching, demultiplexing, wavelength conversion, optical logic. Self-switching in these types of Sagnac interferometers is achieved by breaking the loop symmetry for counter-propagating pulses in the optical fiber. To do this the NOLM uses an asymmetric coupler to induce different phase-shifts by self-phase modulation (SPM). However the symmetric coupler can be used in a NOLM if a gain element is placed asymmetrically in the loop (NALM). In this paper, we report numerical studies of the demultiplexing of short optical soliton and quasi-soliton pulses in the basic terahertz optical asymmetric demultiplexer (TOAD) and in a version composed with a dispersion decreasing and increasing fiber (DDF and DIF respectively) considering a linear profile. We also investigate the effect of using dispersion decreasing fibers profiles on the performance of the TOAD. Four closely shaped profiles named linear, Gaussian, exponential, hyperbolic have been considered. From our study of the dispersion profiles, we suggest the optimum profile, to operate the TOAD

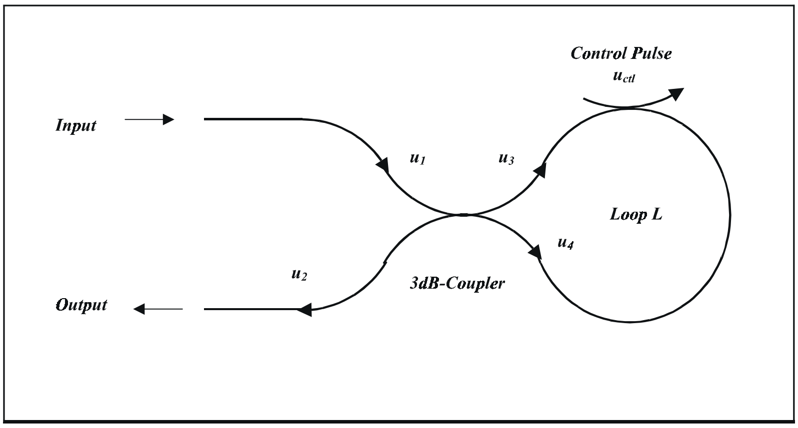
2. Channel demultiplexing using the TOAD

In the terahertz optical asymmetric demultiplexer we use the nonlinear optical-loop mirror (NOLM) constructed by using a fiber loop whose ends are connected to the two input ports of a 3-dB fiber coupler [11] (Figure1). The TOAD has another directional coupler spliced into the fiber loop for the purpose of injecting the control pulses. The control pulses carry sufficiently high power so that the optical nonlinearity of the optical fiber is significantly altered under the action of the control pulses. The clock signal (control pulse), consisting of a train of optical pulses at the signal bit rate is injected into the loop such that it propagates only in the clockwise direction (see figure 1). The OTDM signal enters the NOLM (the input in figure 1) and will be equally split into two counter-propagating directions by the 3-dB coupler. The control signal (clock) introduces a phase shift through cross phase modulation for pulses belonging to a specific channel within the OTDM signal. For a specific signal pulse power and fiber length one has a relative phase shift of π which will result that a single channel is demultiplexed by the NOLM (through output in figure 1). We can say that the NOLM is the TDM counterpart of the WDM ‘add’ and ‘drop’ multiplexers.

3. Pulse Propagation in DDF’s TOAD

We first consider picosecond pulses propagating in the anomalous dispersion regime in an optical fiber with variable normalized second-order dispersion coefficient $\beta_2(z)$. For propagating in DDF, the nonlinear Schrödinger equation with an axially varying dispersion profile $\beta_2(z)$:

$$i\frac{\partial u}{\partial \xi}+\frac{\beta_2(\xi)}{2}\frac{\partial^2 u}{\partial \tau^2}+|u|^2 u=0 \qquad (1)$$



|***Fig. 1 - Schematic of the OTDM using a NOLM configuration.***

where u is the modal field amplitudes in soliton units. ξ and τ are the normalized length and time in soliton units with $\xi = z / L_D$ and $\tau = t / T_0$. Here $L_D = T_0^2/|\beta_2|$, with pulse width T_0 (T_{FWHM} =10ps = 1.763 T_0, $|\beta_2|=20ps^2/km$).The varying GVD parameter $\beta_2(z)$ is normalized by the dispersion in the input of the fiber, $\beta_2(0)=|\beta_2|=20ps^2/km$). For the first order soliton (N=1) the solution is $u_i(\xi,\tau)=A\text{sech}(A\tau)$ and for the quasi-soliton profile we use the solution $u_i(\xi,\tau)=A\text{sech}(\tau)$:

We have analyzed numerically the soliton demultiplexing using the TOAD described before (figure 1). The channel to be demultiplexed is a soliton of 10ps of time duration which is injected in the input (figure 1). For the control pulse we used the soliton and quasi-soliton profiles as discussed before. The output of the TOAD, the demultiplexed channel, under the action of the control pulse was studied for 1,4 and 10 soliton periods ($\xi=\pi/2$, 2π, 5π respectively) for normal telecommunication fiber DDF and DIF fibers. In Figure 1, one has the schematics of the TOAD. The control pulse is injected in the clock wise direction in synchronism with the u_3 pulse (see figure 1). For the DDF profile, the control pulse is seeing a dispersion decreasing fiber. In this paper, we compare three different loop lengths of the loop ($\xi=\pi/2$, 2π, 5π). In this paper, we compare four simple coefficient of dispersion decreasing profiles, namely linear, Gaussian, exponential, and hyperbolic.

Note that in these normalized profiles the dispersion coefficient β_2 monotonically decreases from 1 to a final value of $1/\beta$, after a length L of the coupler.

3-**Results and Discussion**

In this paper we will study the demultiplexing of a fundamental soliton with 10ps of time duration which is injected in the input of the TOAD (see figure 1). The control pulse will be considered with a variable time profile and power. The demultiplexed signal will be obtained at the output of the TOAD (figure 1).

In figures 2 we are considering the TOAD using a DDF fiber. In the soliton regime, the first control power necessary to demultiplex the signal (P_{CTL1}) was 0.72,0.26 and 0.30 for $\xi=\pi/2$, 2π and 5π respectively (see figure 2) , which are shorter when compared with the TOAD with no profile (1.92,0.74 and 0.48 respectively). For the quasi-soliton regime the reduction in power was higher: 0.44, 0.1 and 0.1 for $\xi=\pi/2$, 2π and 5π respectively. In figure 3 we show the profiles of the signal, control pulse and demultiplexed pulse associated to P_{CTL1} in the soliton regime for $\xi=2\pi$. In this figure one has the control pulse (soliton) together with the signal (soliton with time duration of 10ps) and the demultiplexed pulse, which present a strong compression (C_1=2.3) with time duration around 4.3ps.

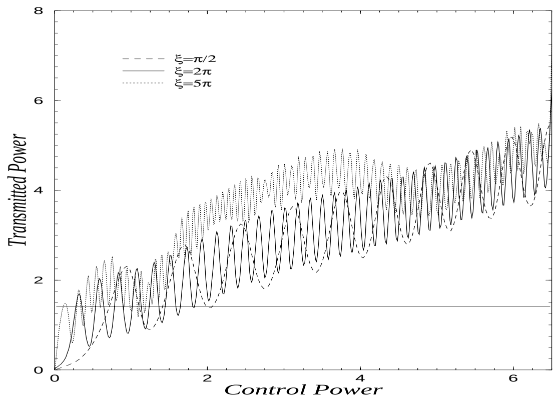


Figure 5a

Figure 2 -Transmitted power against input control power for the TOAD constructed from a DDF with a linear profile, with input pulse of the form Asech(Aτ), α=0.5,β=3, Dashed:$\xi=\pi/2$, Solid :$\xi=2\pi$,: Dotted:$\xi=5\pi$.

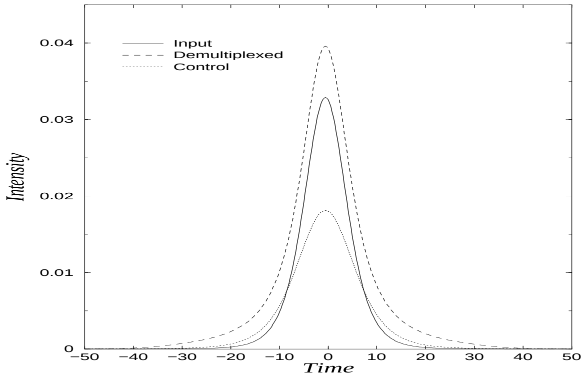


Figure 4c

Figure 3 Intensity profile of Dashed: Demultiplexed pulse , Solid :signal: Dotted: control pulse. For: $\xi=2\pi$, soliton profile, P_{CTL1} = 0.26, C_1 = 2.3

4. Conclusions

In summary, numerical simulations of the basic TOAD operating with an ordinary fiber and with a DDF and DIF (dispersion decreasing and increasing fiber respectively) configurations, for the three length of fiber ($\xi=\pi/2$, 2π and 5π) and for the soliton and quasi-soliton laser profile of the control pulse is reported. The numerical simulations shows that the increase of the fiber length lead to the decrease of the power for the first and second demultiplexed pulses and lead to a broadening of the demultiplexed pulses, with exception to the DDF fiber. This behavior is observed for the soliton and quasi-soliton pumping

Operating the TOAD using a DDF fiber one can say that control power (P_{CTL1}) necessary to demultiplex the signal pulse is always lower compared with the TOAD with the normal telecommunication fiber. This is a strong suggestion that the use of the DDF fiber will allow the use of less control power. We also did simulations with the TOAD operating with DDF in four different profiles: Hyperbolic, exponential, linear and Gaussian .For all the profiles the increase of the length of the fiber also decrease the pump power of the three first peaks for the soliton and quasi-soliton regime. For the $\xi= 2\pi$ fiber with the hyperbolic profile, both soliton and quasi-soliton profiles present the lowest critical power P_{CTL1} and the highest compression factors. For the TOAD with $\xi = 5\pi$ the difference between the fiber profiles and between the soliton and quasi-soliton profiles the are not so dramatic.

References

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