Precise Low-Cost Optical Time Multiplexer based on the Birefringence of Polarization Maintaining Fibers

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Abstract *A novel scheme of optical time multiplexer is presented, based on the high birefringence of polarization maintaining fiber. The scheme is highly precise, and its fiber-only construction reduces the multiplexer loss and cost.*

Introduction

The spreading of internet applications requiring large communication bandwidth is driving a new race for the increase of the bit rate per channel in optical communications, and as the 100Gbps systems are approaching, higher bit rates are challenging the researchers[1,2]. High bit rates nowadays are generated by time multiplexing pulsed signals at lower data rates. The possibility of raising the repetition rate of optical pulses by time multiplexing is gathering the interest of even diverse fields such as optical radar and microwave optics.

The optical time multiplexers (mux) used today are based on the split-and-delay technique: the pulsed signal is equally split on two separate paths, one of which is longer than the other, realizing a delay equal to half the starting repetition rate; the two delayed halves of the signal are then recombined, forming a pulse train with doubled repetition rate. This procedure can be repeated a number of times with subsequent stages. This kind of mux shows many problems: it presents significant optical loss, its correct equalization requires variable attenuators and relies on the precision of the optical splitters, the setting of the time delay needs variable optical delay lines, and the large number of components makes the mux expensive.

Here we present a new scheme of optical mux, which drastically reduces the cost and insertion loss, while improving the equalization capabilities of the multiplexer.

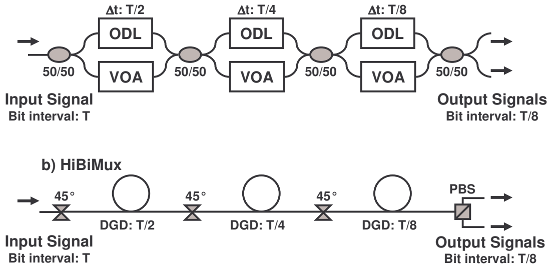

Fig. 1: a) the split-and-delay multiplexer (mux): ODL-optical delay line, VOA-variable optical attenuator. All the components use polarization maintaining (PM) fiber. b) the proposed mux based on high birefringence in PM fiber (HiBiMux). DGD-differential group delay, PBS: polarization beam splitter. The mux is built with PM fiber.

Ordinary split-and-delay mux

The scheme of an ordinary optical mux, today commercially available, is reported in Fig. 1a). It is made of a number of stages, each composed of a 2x2 fiber splitter/coupler with nominal splitting ratio 0.5, a tunable optical delay line (ODL), and a variable optical attenuator (VOA). All the devices must be in polarization maintaining (PM) fiber to assure a single-polarized aggregate signal.

The delay introduced by the longer arm with respect to the shorter, depends on the bit rate at the input of the stage, and is in the order of few ps. Since the manual cut of the fiber has a limited precision of about 1cm, corresponding to a delay of about 50ps, a tunable ODL is necessary with a minimum range of ±50ps and a precision of few fs, which is an expensive device. On the opposite arm of the stage, a variable attenuator is inserted to compensate for the losses introduced by the ODL.

If the fiber splitter/coupler doesn't show a perfect splitting ratio of 0.5, the signals from the two arms (the one with the ODL and the one with the VOA) are mixed at the two output fibers of the coupler with different ratios, and therefore the VOA cannot compensate for the power unbalancing, leading to a non-equalized pulse train. To avoid this problem, one should use 2x1 couplers followed by 1x2 splitters, instead of 2x2 couplers, thus increasing the components count and introducing 3dB of loss for each stage of the mux.

Optical time mux based on birefringence in PMF

The mux structure we are proposing is reported in Fig. 1b) and is based on the high birefringence of polarization maintaining fibers (HiBiMux). Each stage is composed of only a spool of PM fiber, where a linearly polarized signal is inserted with 45° rotation with respect to the principal polarization axes of the fiber: the signal is equally split on the two axes, and the differential group delay (DGD) of the fiber retards the two halves of the signal one with respect to the other. By correctly defining the fiber length, the delay introduced by the DGD is set to half the bit interval of the input signal.

At the end of each stage, the repetition rate of the signal is doubled by time interleaving but it is also

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polarization multiplexed: the signal polarization varies from one principal axis to the other at every pulse. The 45° rotation at the beginning of the next stage then mixes the polarization multiplexed signals into two new principal axes. After the last stage, a polarization beam splitter (PBS) 45° rotated generates two replicas of the time multiplexed signal.

The delay given by the birefringence of the PM fiber is about 1 to 2ps/m, and the precision of a manual fiber cut brings to a delay precision of 10 to 20fs, which is more than enough for multiplexing optical pulses up to 320Gbps and beyond (the time slot for a 320Gbps signal is 3.125ps, the one for a 2.5Tbps is 390fs). Therefore the use of a tunable ODL can be avoided.

The single fiber path of the HiBiMux structure assures the attenuation is the same for every pulse in the output signal. In case some attenuation unbalances are present, due for example to different propagation loss on the two principal axes in the PM fiber, the structure can compensate for them finely tuning the rotation angle of the following junction. So no VOAs are needed.

Moreover, the all-fiber construction of the HiBiMux leads to very low losses. The possibility to use dispersion shifted PM fiber, now commercially available, also allows to realize an optical time multiplexer with minimum effect on pulse shape and width. Finally, a PRBS-maintaining implementation can be designed.

HiBiMUX implementation

To test the proposed multiplexing technique we have realized a 40:320GHz clock multiplexer, as reported in Fig. 2. The exploited pulse source is a mode locked laser driven at 40GHz producing 5ps FWHM pulses at 1550nm, followed by a stage of nonlinear pulse compression leading to 700fs FWHM pedestal-free pulses. The HiBiMux has 3 stages in dispersion shifted PM fiber , with a DGD of 1.5ps/m. The stages have been tailored to the 40GHz pulse source, and the polarization rotations have been realized in air so that every stage could be optimized to obtain an equalized pulsed clock at the mux output. The output signal has been tested using a SHG autocorrelator, and studying the optical spectrum of a CW laser at 1520nm after undergoing XPM due to the multiplexed signal in a spool of highly nonlinear fiber[3]. At the HiBiMux output, few meters of dispersion compensating fiber have been used to compensate for the chromatic dispersion of the fiber in the mux and in the optical amplifier used for signal visualization and analysis.

Fig. 2a) shows the SHG autocorrelation of the 320GHz multiplexed pulse source. The lack of equalization in the autocorrelation trace is due to a limited precision in the SHG analyzer, but the correct periodicity of the autocorrelation peaks confirms the precision in the delays obtained by the proposed mux technique. Fig. 2b) shows the spectrum of the CW laser after being phase-modulated by the 40GHz pulse source. The spectrum is composed of a number of lines spaced by 40GHz (about 0.32nm), centred around the residual CW laser at 1520nm. Fig. 2c) shows the spectrum of the CW laser after phase modulation from the 40:320GHz multiplexed pulsed signal. Most of the lines in the spectrum have been suppressed, and only the lines at 320GHz (2.56nm) from the CW central wavelength survive. The suppression is as high as 13dB. This confirms that the HiBiMux multiplexes the signal with both highly precise delays and equalizations.

The total insertion loss of the developed HiBiMux is 7dB, comprising the 3dB loss of the PBS. Since the 45° rotations have been performed here by in air rotators due to experimental setup needs, this value could also be reduced further by splicing the PM fibres of each stage.

Conclusions

We have proposed a novel scheme for an optical time multiplexer based on the high birefringence of polarization maintaining fiber. The scheme shows precise multiplexing of optical pulses with minimum loss and using almost only optical fiber, thus cutting down the cost of the multiplexer. Experimental results show precise multiplexing from 40GHz to 320GHz.

References

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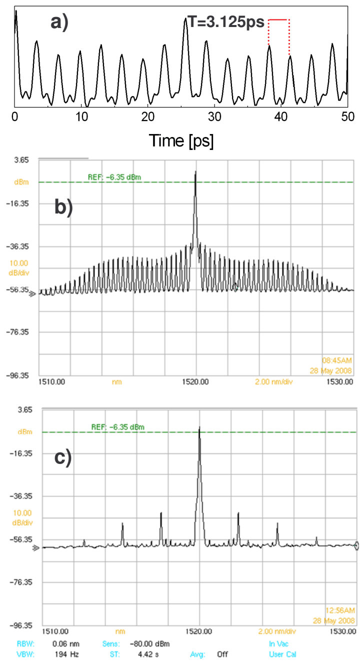

Fig. 2: a) SHG autocorrelation of the 40:320GHz multiplexed pulse laser. b) Optical spectrum of a CW laser phase-modulated by the 40GHz pulse source. c) Optical spectrum of the same CW laser phase-modulated by the 40:320GHz multiplexed signal.