Continuously-Tunable Dispersionless 44-ns All Optical Delay Element
Using a Two-Pump PPLN, DCF, and a Dispersion Compensator

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Abstract We demonstrate an optically controlled, continuously-tunable dispersionless optical delay element using a two-pump PPLN waveguide, dispersion compensated fiber and a dispersion compensator. A continuous optical delay up to 44-ns is shown for 10-Gb/s NRZ applications.

Introduction
Optical delay lines have many potential uses in optical systems, including: (i) buffers for efficient contention resolution in a packet-switched network, (ii) synchronization of multiple bit streams through a high-speed optical switch, and (iii) various optical signal processing techniques for equalization. Such optical delays should optimally be continuously tunable over a wide range of delay times. For example, delays that can vary over a few tens of nanoseconds (i.e., the length of a 10-Gbit/s ATM data packet) have utility as packet buffers.

Discretely tunable optical delay lines have been demonstrated by switching pulses out of recirculating loops [1] or different lengths of fiber [2]. Alternatively, continuously tunable delays have been demonstrated: (i) using fiber parametric amplifiers and a dispersive fiber for a 1.2-ns delay [3] (ii) using slow light techniques for a 1.5-ns delay at a bit-rate of 20 Gb/s [4], (iii) using resonant optical filters [5]. Moreover, many techniques tend to introduce some chirp or dispersion on the optical data stream as it passes through the network element, something that should probably be avoided for optimal system performance.

In this paper, we demonstrate a continuously-tunable dispersionless 44-ns optical delay element using a two-pump periodically-poled lithium-niobate waveguide (PPLN), dispersion compensating fiber (DCF), and a fiber-Bragg-grating (FBG)-based dispersion compensator. The PPLN waveguide is used as a wideband rapidly tunable wavelength converter [6], and is used as the delay selection element. The large dispersion value of the DCF results in a time delay as a function of input wavelength. While intra-band dispersion from the DCF can result in signal degradation, the FBG serves as a compensator before exiting the module. A continuous optical delay up to 44 ns is demonstrated on a 10-Gb/s NRZ system. The wavelength of the output signal is the same as the input signal and this technique is not limited by the speed or modulation format of the signal.

Concept and experimental setup

Our experimental setup is shown in Fig. 1(b). The input signal is a 1546.7 nm 10-Gb/s NRZ signal and is used as the first pump of the 2-pump-PPLN waveguide. LD1 is used as the second pump which should be located equidistant to the center wavelength of the PPLN waveguide. LD2 is used as the dummy/tuning signal which is also equidistant to the center wavelength with respect to the desired output. The output signal wavelength is set by tuning the dummy signal (LD2) wavelength. These three are coupled together, amplified and sent into the PPLN waveguide with center wavelength 1551.3nm. The converted signal is then filtered out and passed through a spool of DCF with dispersion around 1900 ps/nm. After that, the delayed, converted signal is...
converted back to the original wavelength using a second PPLN waveguide with identical center wavelength. By tuning the dummy/tuning laser wavelength, the output delay can be tuned. A chirped FBG with positive dispersion around 2000 ps/nm is used to compensate the intra-channel dispersion arising from the DCF. As the input wavelength is pre-determined, any dispersion compensation module with the correct dispersion value and wavelength is sufficient.

Results and discussion

Fig. 2 shows sample optical spectra and eye diagrams after the 1st PPLN waveguide, 2nd PPLN waveguide, and final output. PPLN generally do not add extra noise to the signal and has almost no speed limitation. However, since the PPLN waveguides used in this experiment has relatively low conversion efficiency, the output signal contains certain amount of ASE noise from the EDFA, and a visible degradation is observed. This problem could be solved by increasing the PPLN conversion efficiency by a few dBs.

Fig. 3 shows the tunable delay as a function of the wavelength of tuning laser (which will determine the converted signal wavelength). Fig. 3(a) shows the bits of a 500-Mb/s signal when the tuning laser is tuned from 1539.40 nm to 1564.92 nm. A 44 ns delay is observed. Fig. 3(b) shows the bits of a 10-Gb/s signal when the tuning laser is set from 1548.40 nm to 1549.42 nm. Fine tuning of the delay line is accomplished by fine tuning the tunable laser. Fig. 3(c) shows the delay time vs. tuning laser wavelength. The slope of the curve is approximately the dispersion of the DCF (regardless of the dispersion from other components).

BER measurements are taken for two different situations, shown in Fig. 4. We believe that the power penalty arises from the dual pass through the low-efficiency PPLN waveguides and the slight mismatch of the dispersion value between the DCF and the FBG. This can be improved through the use of a higher efficiency PPLN waveguide and a more precise system design.

References