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Transmission enhancement by deployment of interferometric wavelength converters within all-optical cross connects

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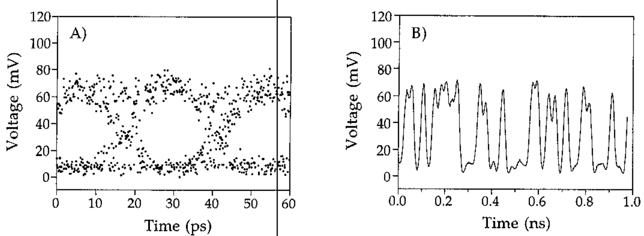
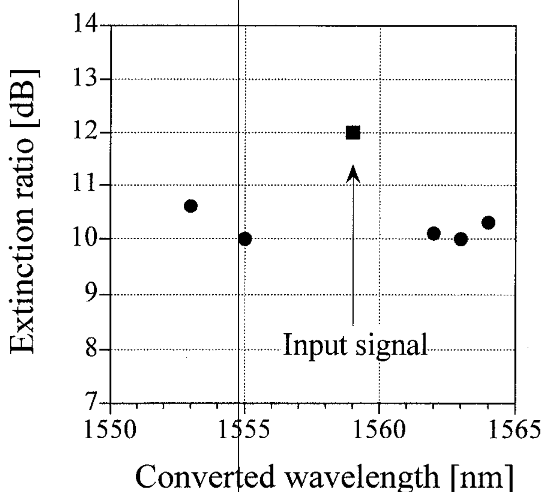


TuO1 Fig. 2. (A) Eye diagram and (B) waveform for 40-Gbit/s converted signal at 1562 nm. Signal-to-ASE ratio (in 1 nm) is 27 dB; signal input power (in the fiber): 8 dBm; cw power: 9 dBm.



TuO1 Fig. 3. Extinction ratio of converted signals versus the converter output wavelength. Signal-to-ASE ratio for all converted signals is >25 dB (in 1 nm).

structures that result in a very simplified and compact device with a total length of only 1.3 mm. Importantly, the optimized MQW stack layer with the vertical layer stack containing a 10-well tensile-strained InGaAs/InGaAsP waveguide core results in a high differential gain and a high confinement factor enabling very high-speed operation.[5]

To assess the system performance of the MI converter at 40 Gbit/s a RZ input signal is generated by a gain-switched DFB laser emitting short pulses followed by passive delay-line multiplexers and a 20-Gbit/s Mach-Zehnder modulator (see Fig. 1). The signal is coupled directly to one of the interferometer arms at the highly reflective input port (right facet in Fig. 1). The resulting phase difference between the two interferometer branches alternates with the digital information of the input signal due to carrier depletion. Wavelength conversion is obtained as cw light at the desired output wavelength is coupled to the AR-coated input port of the coupler section (left facet in Fig. 1) and experiences the modulation of the MI transfer function. The cw light to the MI converter is provided by a tuneable laser source. At the converter output an optical circulator and a tuneable filter select the converted signal.

Figure 2 illustrates the fine conversion capability by a 40-Gbit/s converted eye diagram and a pulse trace for conversion from 1559–1562 nm (up conversion) with a signal input power to the converter of 8 dBm. High-speed all-optical wavelength conversion is demonstrated by the clear eye diagram showing ~10 dB extinction ratio. Additionally, it is important to note that the converted signal is not inverted compared to the input and that the signal-to-ASE ratio is as high as 27 dB in 10-nm bandwidth.

The wavelength sensitivity is analyzed in Fig. 3 that gives the extinction ratio for the 40-Gbit/s converted signals versus the converter output wavelength. Impressive performance for both up and down conversion is obtained with ~10-dB extinction ratio and >25 dB signal-to-ASE ratio (1 nm) for all wavelengths.

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TuO2 — 4:45pm

Transmission enhancement by deployment of interferometric wavelength converters within all-optical cross connects

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Wavelength-division multiplexing (WDM) networks are expected to utilize all-optical cross connects (OXCN) for signal routing. Because a signal path is likely to contain a number of OXCNs, their cascadability is essential. Furthermore, because wavelength converters in the OXCNs improve traffic performance and ease network management,[1] their cascadability, in particular, is important. Using interferometric wavelength converters (IWCs) we have previously demonstrated experimentally a cascade of 10 converters at 10 Gbit/s with <2-dB penalty.[2] In this paper we analyze the cascadability limitations of OXCNs deploying IWCs.

The wavelength converters used in the experiments and in this analysis are interferometric wavelength converters, where semiconductor optical amplifiers (SOAs) are used as optically controlled phase shifters in a Michelson configuration.[3,4] Converters based on this principle have the capability of pulse reshaping due to their sinusoidal transferfunction and small chirp.[5]

Importantly, when cascading nonlinear devices such as IWCs, the resulting transfer function is not the product of the individual IWC transfer functions. Here we show by detailed modeling that IWCs are cascadable in large numbers (>30) at 10 Gbit/s and their reshaping capability enhances the possible transmission distance when interconnected by nondispersion-shifted (NDS) fiber. The modeling shows excellent agreement with experiments.[5]

In networks where the OXCNs are interconnected by dispersion-compensated fiber (zero accumulated dispersion between OXCNs), pulse distortion along the signal path arises during conversion. The effect of this pulse distortion is seen in Fig. 1, where the penalty for a

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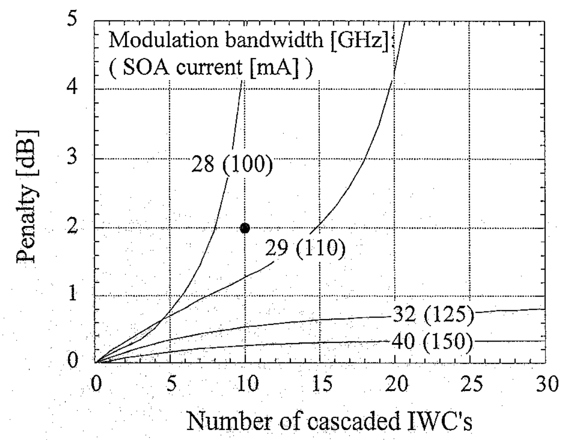
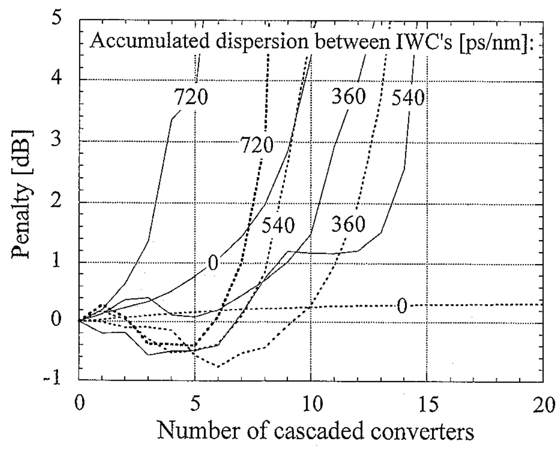
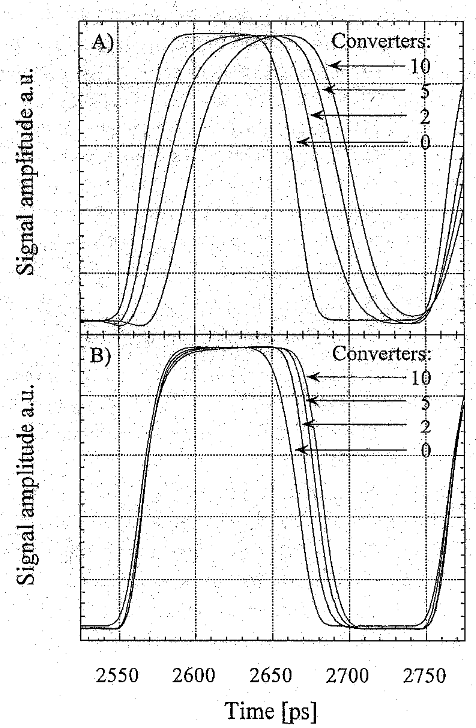


TuO2 Fig. 1. Penalty as function of number of cascaded converters with the modulation bandwidth (SOA current) of the converters as parameter. Perfect fiber dispersion compensation assumed between the converters (no accumulated dispersion between the converters). (●) experimental point from loop experiment with I_{bias} ~110 mA.



TuO2 Fig. 3. Penalty as function of number of cascaded converters with the accumulated fiber dispersion between the converters as parameter for a bias current of 100 mA (full lines) and 150 mA (dashed lines).

10-Gbit/s signal as function of the number of cascaded IWCs is shown. For a bias current of 100 mA (modulation bandwidth of each IWC ~28 GHz) five converters can be cascaded with 1-dB penalty. Increasing the bias current to 150 mA and thereby the modulation bandwidth to ~40 GHz,[3] the number of possible converters is >30. The effect of insufficient IWC bandwidth is seen in Fig. 2, which illustrates a part of a PRBS after 0, 2, 5, and 10 converters for SOA currents of: A) 100 mA and B) 150 mA. Clearly, the IWCs biased with 100 mA are too slow resulting in a penalty of >5 dB after 10 converters, whereas the converters biased with 150 mA can follow the 10 Gbit/s signal.



TuO2 Fig. 2. Part of PRBS before transmission and after 2, 5, and 10 converters for a SOA current of A) 100 mA and B) 150 mA.

In case of imperfect dispersion compensation between the converters, pulse distortion also arises during fiber transmission. However, when transmitting converted signals through NDS fiber, the small chirp of the IWCs results in an initial pulse compression, which can be equalized by the converters.[5] This reshaping requires only a moderate bandwidth of the IWCs as shown in Fig. 3, that gives the penalty as function of the number of converters with the accumulated fiber dispersion as parameter. The number of IWCs possible for a bias current of 100 mA (solid lines) is enhanced from 5 to 9 with the insertion of 30 km of NDS fiber. Increasing the NDS fiber span increases the pulse distortion beyond IWC reshaping capability and a fast deterioration is observed. No enhanced transmission distance is obtained by increasing the bias current to 150 mA (dashed lines), because the narrowed pulses are maintained at the output of the converter giving rise to an increasing impact from fiber dispersion throughout the link.

In summary, we have shown that interferometric wavelength converters with adequate bandwidth improve transmission performance. We predict that more than 30 converters can be cascaded at 10 Gbit/s.

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