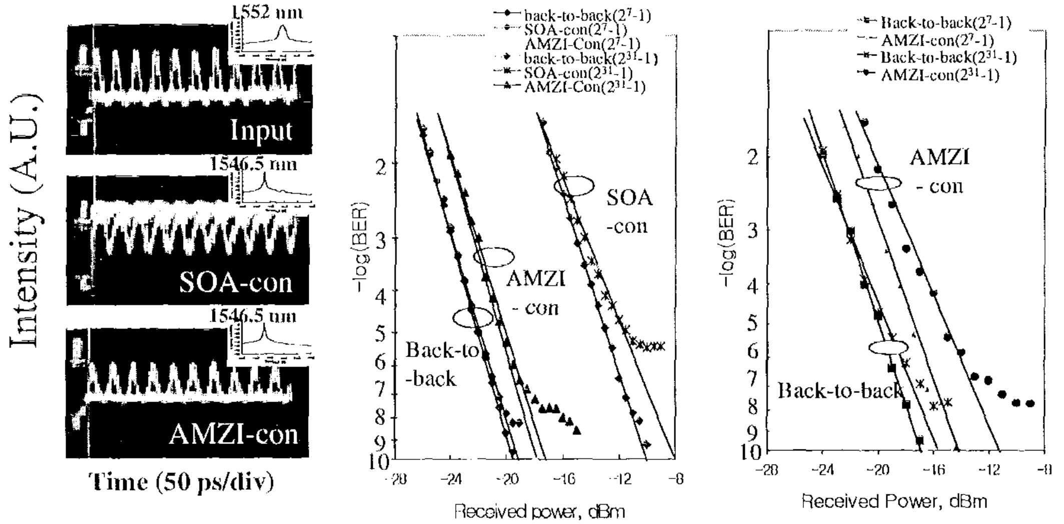

(a) (b) (c)

CWI3 Fig. 2. (a) Eye diagrams for 20 Gb/s RZ data, (b) BER performance for 10 Gb/s RZ data, and (c) BER performance for 20 Gb/s RZ data.

conversion, respectively. The lengths of pseudorandom binary sequence of the input signal are $2^7 - 1$ and $2^{31} - 1$. In the case of the SOA-conversion as shown in Fig. 2(a), the wavelength conversion was achieved by the XGM alone, and the output was inverted with respect to the input. When the AMZI was in place, a larger eye-opening was realized with an increased extinction ratio and with an apparently faster response. Fig. 2(b) shows the bit-error-rate performance of the wavelength converter for $2^7 - 1$ and $2^{31} - 1$ long RZ PRBS at 10 Gb/s with and without AMZI. When the AMZI was removed, the inverted output displayed a power penalty of 8 dB at 10^{-10} BER. Fig. 2(c) shows the bit-error-rate performance of the wavelength converter at 20 Gb/s measured with demultiplexing by the NOLM to 10 Gb/s. The power penalty reduced down to 3.5 dB.

In conclusion, we have successfully demonstrated an all-optical wavelength conversion scheme for RZ format data input of 20 Gb/s by using a SOA-XGM converter incorporated with a stabilized AMZI. In this scheme, we could achieve a wavelength conversion speed not limited by the slow carrier recombination rate of SOAs. The scheme also provided a non-inverting wavelength conversion. This scheme may be useful in practical WDM communication systems with a high speed channel bit rate.

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CWI4 **11:00 am**

Wavelength dependence and power requirements of a wavelength converter based on XPM in an optical fiber

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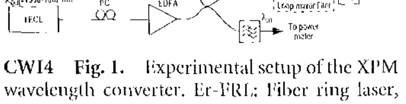
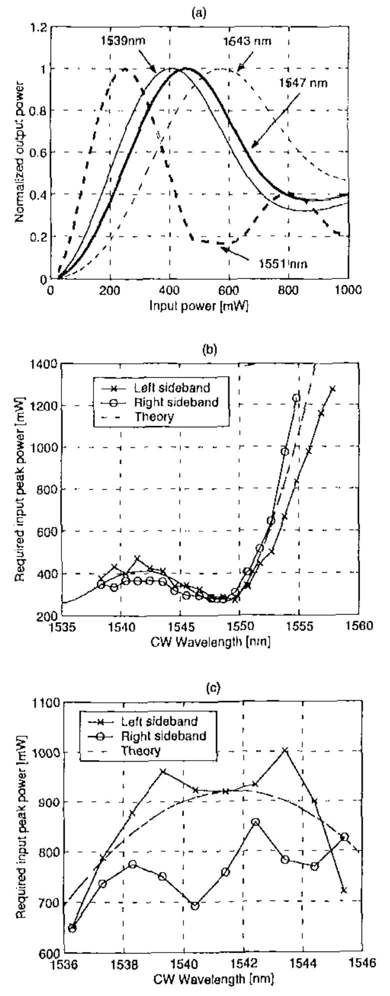
All-optical wavelength conversion can play an important role in future ultra-high-speed networks due to the significant increase in flexibility and potential reduction in need for optical buffers.[1] Ultra-high-speed speed wavelength conversion of return-to-zero (RZ) has previously been demonstrated using four-wave mixing in fiber[2] and SOAs[3] and by use of cross-phase modulation in the nonlinear optical loop mirror (NOLM).[4] Schemes using XPM and soliton formation[5] or XPM and polarization discrimination[6] have previously been proposed. We have recently demonstrated a different XPM-based scheme to wavelength convert 40 Gb/s RZ data.[7]

The basic idea of this scheme is to utilize XPM in a dispersion shifted fiber. Continuous wave (CW) light is launched into the fiber along with the data pulses. The pulses will impose a phase modulation which generates sidebands on the CW light. After suppression of the original CW wavelength, and filtering out one of the sidebands, the wavelength converted data remains at the output. Here we report on pulse measurements in the wavelength converter in order to assess its fundamental operating characteristics. Figure 1 shows the experimental setup where pulses were generated from an actively mode-locked Erbium-doped fiber ring laser generating 8 ps pulses with a repetition rate of 10 GHz. The pulses were modulated and combined with CW light from a tunable external-cavity laser, and sent through 5 km of dispersion shifted fiber with a zero-dispersion wavelength of 1543 nm. After the fiber, a loop-mirror filter was used to notch out the original CW light, and a 0.4 nm band-pass filter was used to select one of the two generated sidebands. The loop-mirror filter has a sinusoidal filter function with repetitive notches, separated by 1 nm. An optically preamplified receiver and a sampling oscilloscope was used to measure the pulse characteristics. The pulse power was monitored at one port of the combiner.

In the first experiment pulses at 1535 nm were converted to longer wavelengths, and the CW light was changed from 1538 nm to 1558 nm. Depending on which sideband is chosen, the behavior is somewhat different. For the left sideband, the output pulse width of 12 ps is essentially transform limited over this wavelength range and given by the optical filter bandwidth. The right sideband shows the same behavior up to 1550 nm where the pulse width starts to increase, due to asymmetric spectral broadening. In terms of optical power, the input-output transfer function has a nonlinear shape shown by simulation in Fig. 2a for different wavelengths. When the wavelength separation between the pump and the CW light increases, the input pulse power required for maximum output power increases due to dispersive walk-off between the input pulses and the CW light. The input pulse power is then distributed over a time slice of the CW light which corresponds to this walk-off. As shown in Fig. 2b, the required input power for



CWI4 Fig. 1. Experimental setup of the XPM wavelength converter. Er-FRL: Fiber ring laser, TECL: Tunable External Cavity Laser, MOD: Mach-Zehnder modulator, EDFA: Erbium-doped fiber amplifier, PC: Polarization controller, PMF: Polarization maintaining fiber, DSF: Dispersion shifted fiber.



CWI4 Fig. 2. (a) Simulated transfer functions of the wavelength converter. (b, c) Required input power to reach the maximum of the transfer function. Input pulses at (b) 1535 nm and (c) 1553 nm.

maximum output power increases when the wavelength is changed from 1538 nm to the zero-dispersion wavelength, where it decreases until the walk-off is zero around 1550 nm. At this point the required power starts increasing very rapidly, due to higher dispersion. This behavior can be explained from simple theory. If dispersion and loss are neglected, the frequency shift of the CW light for Gaussian pulses can be described by $\Delta f \sim P_{in}L[\exp(-(t-\beta)^2) - \exp(-t^2)]/\beta$ where P_{in} is the input power, L the fiber length, and β the walk-off. In this equation, an increased β requires an increased power for the same frequency shift. The result of such an analysis is shown together with the measured data in Fig. 2b and c. In a second experiment we show conversion of pulses at 1553 nm to shorter wavelengths. Figure 2c shows that the required input power has a similar shape as for upconversion. However, this turns out to be more difficult, because the pump is located in the anomalous dispersion regime, where the spectral broadening is much more significant than in the normal dispersion regime. When the separation between the two wavelengths gets smaller, the spectrally broadened input pulses will interfere with the CW light, which generates interferometric noise in the output pulses. This effect starts to be significant at 1547 nm.

This type of wavelength converter has a polarization dependence of 5 dB originating from the underlying XPM process. However, it can probably be made polarization independent by use of polarization scrambling in the dispersion shifted fiber.[8,9] By using a highly nonlinear fiber,[10] it is possible to have shorter fibers, which will increase the optical bandwidth due to lower dispersive walk-off. Also, the scheme is probably scalable to even higher bit rates, where the filtering of the optical signal would actually by simpler due to the larger separation of the generated sidebands.

**on leave from Dept. of Electronics, Royal Inst. of Tech., Sweden*

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CWI5 11:15 am

All optical front end error correction on a spectral data bus

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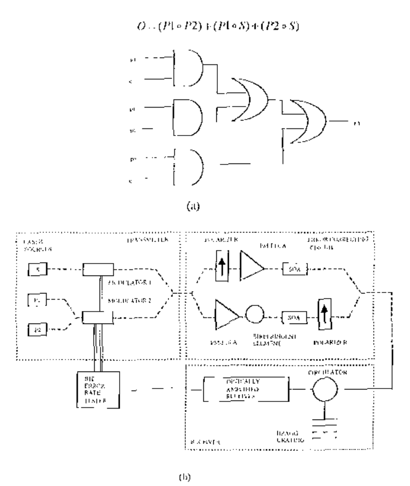
Ultra-fast byte-wide data transmission between high-speed computers can be achieved using a spectral data bus where each bit is assigned a different wavelength and data is transmitted on one optical fiber.[1,2] All-optical signal processing for header recognition, routing, error correction or encryption can improve the throughput of a cluster of linked computers. All-optical logic operations on PolSK (Polarization Shift Key) coded data using FWM (Four-Wave Mixing) in SOAs (Semiconductor Optical Amplifiers) which exploit the polarization properties of the nonlinearity[3] have been proposed and demonstrated.[4,5] Furthermore, FWM on PolSK coded bits can be used to construct higher-level logic elements to implement truth tables involving several WDM (Wavelength Division Multiplexed) data bits without resorting to elemental Boolean functions such as NAND/NOR.

In this paper we demonstrate all-optical EC (Error-correction) on a (3,1) Hamming Code. The 3-bit word consists of one data-bit accompanied by two check-bits. Information is polarization coded (orthogonal polarization of the electric field, each along the principal axes of a PM fiber, represent the logical "1" and "0") and parallel transmission is achieved by putting each bit on a different WDM channel. The Boolean operation related to the (3,1) Hamming code along with the schematics of its implementation is shown in Fig. 1. The EC circuit consists of two synchronized arms each having a pre-processing element and a SOA. FWM occurs in the arm with the polarizer before the SOA when all bits are identical (i.e. no errors). The other arm has a birefringent element which acts as a half-wave plate for one



CWI5 Fig. 1. (a) Boolean circuit for error connection on the (3,1) Hamming Code (b) Schematic of the experimental set-up (dashed lines indicate PM fiber).