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1. L.F. Tiemeijer, P.J.A. Thijs, T. van Dongen, J.J.M. Binsma, E.J. Jansen, H.R.J.R. van Helleputte, IEEE Photon. Technol. Lett. **7**, 284–286 (1995).
2. P.J.A. Thijs, L.F. Tiemeijer, J.J.M. Binsma, and T. van Dongen, IEEE J. Quantum Electron. **30**, 477–499 (1994).
3. V.G. Mutalik and L.F. Tiemeijer, in *Proceedings of the NCTA 1996*, pp. 307–312.
4. G.N. van den Hoven, L.F. Tiemeijer, P.J.A. Thijs, T. van Dongen, J.J.M. Binsma, E.J. Jansen, *Optical Amplifiers and Their Applications*, Vol. V, 1996 Trends in Optics and Photonics Series (Optical Society of America, Washington, D.C., 1996), p. 16.
5. B. Clesca, P. Bousselet, J. Auge, J.P. Blondel, H. Fevrier, IEEE Photon. Technol. Lett. **6**, 1318–1320 (1994).

ThG5 (Invited) 11:30am

Semiconductor device and lightwave system performance modeling

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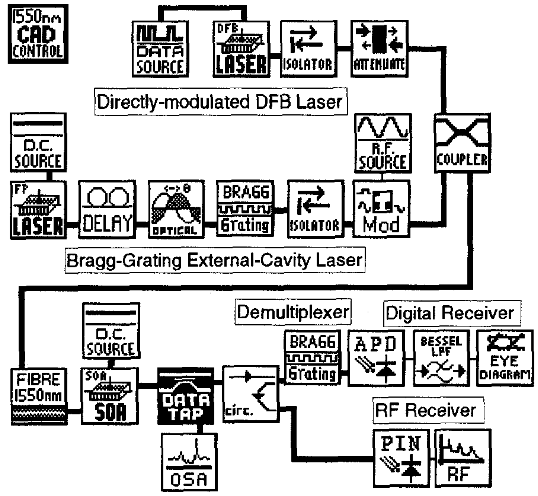
Optical fiber communications is changing. The interests of researchers are being driven towards short-term developments of novel network concepts in the areas of fiber-to-the-home, wavelength-division multiplexing (WDM), wavelength and space switching, to name a few. Device researchers must consider the applications of their devices, and systems designers must compare the technological difficulties of their proposals. Photonic circuits are emerging, including circuits for wavelength switching, format conversion, and clock regeneration. There is a growing interest in analog applications of optical fibers, such as millimeter-wave antenna feeds for pico-cell mobile systems.

One aid to the designer/researcher is photonic computer-aided design/engineering (CAD/CAE). CAD software enables ideas to be tested, then rejected or optimized, without the cost and delay in developing prototypes.[1,2] Photonic-CAD identifies design errors due to component interactions, and can be used to convince OEM purchasers of the value of a component in their system, without them having to disclose the nature of a system. Photonic-CAD, in essence, offers all the advantages of electronic CAD; advantages that we now take for granted and could not do without.

This presentation demonstrates the Optoelectronic, Photonic and Advanced Laser Simulator (OPALS),[3] developed by the Australian Photonics Cooperative Research Centre, as an example of a photonic CAD package suitable for large-signal wide-optical-bandwidth semiconductor device and lightwave system performance modeling.

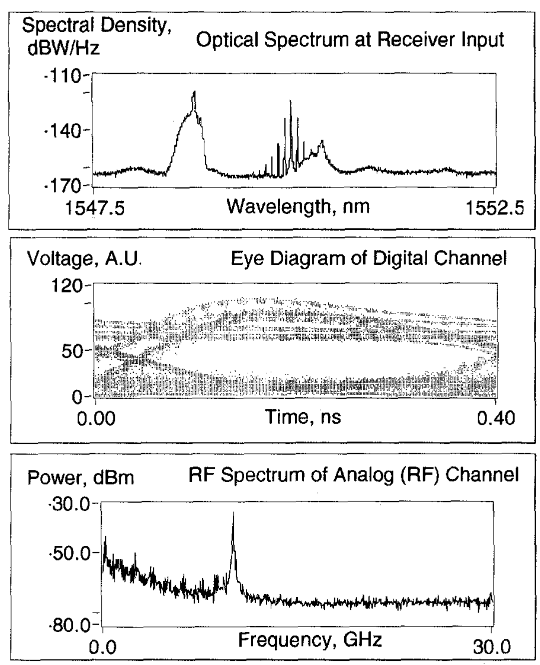
Figure 1 shows an OPALS schematic diagram of a photonic system designed to illustrate the modeling of mixed analog-digital systems, with multiple optical carriers, and multiresonator devices as transmitters. The analog channel is produced by a 1550-nm fiber-Bragg-grating stabilized Fabry-Perot laser,[4] externally modulated with a 10-GHz RF carrier. This is combined with the output of a 2.5-Gbit/s directly modulated 1549-nm DFB laser, before transmission through 40 km of fiber and amplification by a semiconductor optical amplifier (SOA). The received signal is demultiplexed using a Bragg grating and circulator. The RF channel is



ThG5 Fig. 1. OPALS schematic diagram of a mixed analog/digital system.

monitored by an RF spectrum analyzer, and the digital channel is displayed on an eye diagram.

Figure 2 shows the outputs of the simulation. The optical spectrum analyzer (OSA) displays the chirp-broadened digital carrier, and the analog carrier with side-bands and distortion products sitting on a side-mode of the digital channel laser. The eye diagram shows performance degradation due to factors such as cross talk, fiber dispersion, SOA dynamics, bandwidth limitations and SOA noise.[4] The RF spectrum shows a 10-GHz carrier, with considerable broadening and low-frequency noise, due to cross talk, amplifier noise and nonlinearities. These effects can be isolated in OPALS, enabling rapid system optimization.



ThG5 Fig. 2. Simulated optical spectrum, eye diagram and RF spectrum showing complex interactions.

In conclusion, the role of the photonics designer is changing, with photonic networks becoming more complex. CAD can speed the design process, by predicting device performance, and the interaction of devices within systems. The most promising design options can be selected then optimized before building prototypes, reducing both design cost and time.

1. A.J. Lowery, P.C.R. Gurney, X.-H. Wang, L.V.T. Nguyen, Y.C. Chan, M. Premaratne, Proc. SPIE **2693**, 624–635 (1996) and references therein.
2. A. Elerfaie, LEOS Newsletter, 7, 1, 19 (1993) and references therein.
3. The Optoelectronic, Photonic and Advanced Laser Simulator (OPALS) is a product of Virtual Photonics Pty Ltd, Australia (info@vp.com.au).
4. A.J. Lowery, IEE Proc. J. Optoelectron. **139**, 180–188 (1992).

ThH 10:30am–12:00m

Ballroom C3

High-Speed TDM II

N.J. Doran, *Aston University, U.K., Presider*

ThH1 10:30am

Demonstration of high-dispersion tolerance of 20-Gbit/s optical duobinary signal generated by a low-pass filtering method

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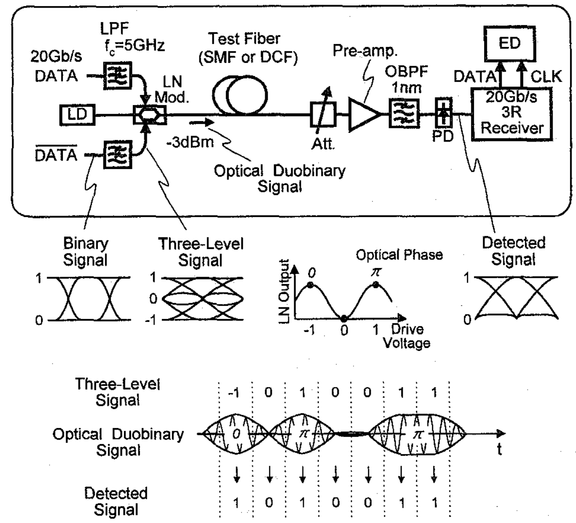
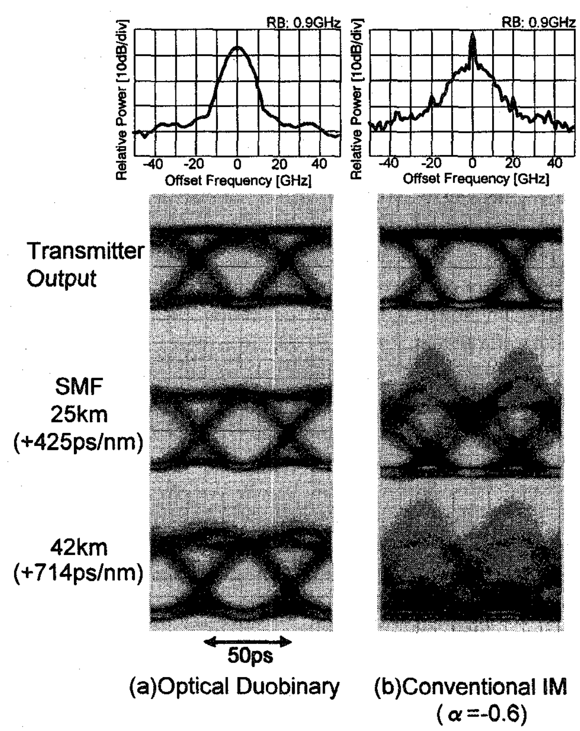
Waveform distortion due to fiber chromatic dispersion in a high-speed optical transmission system is a serious problem. An effective way to avoid this distortion is the use of an optical duobinary signal,[1–4] which has only half the spectrum bandwidth of a conventional intensity modulation (IM) signal. For generating optical duobinary signals, two types of modulation schemes are well known; a low-pass filtering (LPF) method[2,4] and an electrical one-bit delay method.[3] From computer simulation results for both modulation schemes, we have found that the LPF method shows larger suppression for the optical spectrum side-lobes and has more tolerance against the fiber dispersion than the one-bit delay method. Therefore, we employed the LPF method to evaluate dispersion tolerance of the optical duobinary signal. By using a newly developed, high-speed optical duobinary transmitter and receiver, more than 40-km standard fiber [1.3-μm zero-dispersion single-mode fiber (SMF)] transmissions have been demonstrated at 20 Gbit/s for the first time, to our knowledge. The result indicates the robustness of optical duobinary signals against dispersion in high-capacity, long-distance transmission.

Figure 1 shows our experimental setup. To generate an optical duobinary signal with low inter-symbol interference (ISI), a 20-Gbit/s D-type flip-flop IC with complementary binary outputs and high linearity modulator drivers were used. The pre-coded 20-Gbit/s NRZ binary signals are converted to three-level duobinary signals with 5-GHz fifth-order Bessel-Thomson LPFs. These three levels are mapped into optical '+1', '0', '−1' levels with a push-pull-type $LiNbO_3$ (LN) Mach-Zehnder modulator. The '+1' and '−1' levels have the same intensity but opposite phase, as shown in



ThH1 **Fig. 1.** Experimental setup and corresponding operating conditions for 20-Gbit/s optical duobinary transmission.

Fig. 1. The dispersion tolerances were evaluated by transmitting the signal at a signal wavelength of 1.55 μm through two different types of test fibers, i.e., SMFs with anomalous dispersion (Dispersion; $D > 0$), and dispersion-compensating fibers (DCFs) with normal dispersion ($D < 0$). The original binary signal is recovered by the square-law detection process at a 20-Gbit/s 3R receiver. For back-to-back reception, −28.5 dBm sensitivity at 10^{-9} bit error rate (BER) was obtained.



ThH1 **Fig. 2.** Measured optical spectra and waveforms for 20-Gbit/s optical duobinary and conventional IM signals before and after transmission over 25 km (+425 ps/nm) and 42 km (+714 ps/nm) SMFs.