10 Gb/s SCM System Using Optical Single Side-band Modulation

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Abstract

A 10Gb/s SCM long-haul optical system is reported. 4 x 2.5Gb/s data streams are combined into one wavelength, which occupies a 20GHz optical bandwidth. Optical SSB is used to increase bandwidth efficiency and reduce dispersion penalty.

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In order to use the optical bandwidth provided by optical fibers more efficiently, new transmission technologies have been developed rapidly in recent years, such as TDM, WDM, and their combinations. Apart from noise accumulation, high-speed TDM optical systems suffer from chromatic dispersion, nonlinear crosstalk, and polarization-mode dispersion (PMD). Optical systems with data rates of 10 Gb/s and higher require precise dispersion compensation and careful link engineering. On the other hand, WDM technology uses lower data rates at each wavelength. However, due to the limitations in the wavelength stability of semiconductor lasers and selectivity of optical filters, the minimum channel spacing is ~50 GHz in current commercial WDM systems. Further improvement of optical bandwidth efficiency remains a challenge.

A significant advantage of sub-carrier multiplexing (SCM) is that microwave devices are more mature than optical devices: the stability of a microwave oscillator and the frequency selectivity of a microwave filter are much better than their optical counterpart. A popular application of SCM technology in fiber optic systems is analog CATV distribution [1]. Because of the simple and low-cost implementation, SCM has also been proposed to transmit multi-channel digital optical signals using direct detection [2] for local area optical networks.

In this paper, we demonstrate a 10 Gb/s SCM digital optical fiber system for long haul applications. Four channels of 2.5 Gb/s data streams are carried by one optical carrier and the composite signal occupies a 20 GHz optical bandwidth. This 10Gb/s composite optical signal is transmitted over 150-km equivalent standard single-mode fiber (SMF) without dispersion compensation. Optical single sideband modulation (SSB) is used to increase optical bandwidth efficiency and to reduce the dispersion penalty. The combination of SCM and WDM provides a more flexible platform for high-speed optical transport networks with high optical bandwidth efficiency and high dispersion tolerance.

The basic configuration of an SCM/WDM optical system is shown in Fig.1. In this example, *n* independent high-speed digital signals are mixed by *n* different microwave carrier frequencies f_i. These are combined and optically modulated onto an optical carrier. *m* wavelengths are then multiplexed together in an optical WDM configuration. At the receiver, an optical demultiplexer separates the wavelengths for individual optical detectors. Then, RF coherent detection is used at the SCM level to separate the digital signal channels. Channel add/drop is also possible in both wavelength level and SCM level. While this SCM/WDM is, in fact, an ultra-dense WDM system, sophisticated microwave and RF technology enables the channel spacing to be comparable to the baseband, which is otherwise not feasible by using optical technology. Compared to conventional high-speed TDM systems, SCM is less sensitive to fiber dispersion, because the dispersion penalty is determined by the width of the baseband of each individual signal channel. Compared to conventional WDM systems, on the other hand, it has better optical spectral efficiency because much narrower channel spacing is allowed.

Conventional SCM generally occupies a wide modulation bandwidth, because of its double-sideband spectrum structure, and, therefore is susceptible to chromatic dispersion. In order to reduce dispersion penalty and increase optical bandwidth efficiency, optical SSB modulation is essential for long-haul SCM/WDM optical systems. Fortunately, optical SSB is relatively easy to accomplish in SCM systems, because there are no low frequency components, and Hilbert transformation is thus much simpler than in conventional TDM systems [3].

In order to investigate the feasibility of long-haul digital SCM transmission at high speed, an experiment was conducted at 10Gb/s capacity per wavelength. Four 2.5Gb/s digital signals were mixed with four microwave carriers each at 3.6 GHz, 8.3 GHz, 13 GHz and 18 GHz. They were then combined and amplified to drive a dual electrode $LiNbO_3$ Mach-Zehnder modulator with a 20 GHz bandwidth. As shown in Fig.2, in order to generate optical single-side, the composite signal was applied to both of the two balanced electrodes with a $\pi/2$ phase shift in one of the arms using a 90^o hybrid splitter. A dc bias sets the modulator at the quadrature point to generate optical SSB [4]. Fig.3 shows the SSB optical spectrum measured by a scanning Fabry-Perot interferometer with 1GHz resolution bandwidth.

To measure the transmission performance, this optical signal was then launched into a single-mode fiber link with accumulated chromatic dispersion of –2640 ps/nm, which is equivalent to approximately 160 km of standard single-mode fiber. Due to the limitation of fiber availability, the experiment was performed in dispersion compensating fibers (DCF), which have large negative dispersion values. No dispersion compensation was used. At the receiver, the optical signal was pre-amplified and detected by a wideband photo-detector. The composite signal measured by an RF spectrum analyzer after the photo diode is displayed in Fig.4, which clearly shows four separate RF tones. The digital signal was then down-converted to the each individual baseband by mixing the composite signal with local RF oscillators, and then passing through a 1.75 GHz baseband filter. Bit-error rate was measured for all four channels both back-to-back and over the fiber. The measured BER plotted as a function of received optical power level is shown in Fig. 5. The measurement was performed under the condition that all four SCM channels were simultaneously operated. At the BER level of 10^{-10}, the back-to-back sensitivity ranges from –25 dBm to –27 dBm for different channels due to the ripples in the microwave devices. After transmission, the sensitivity is degraded by typically 2.5 dB. In our experiment, this degradation was largely attributed to the frequency instability of the local oscillators. Although the minimum allowed channel spacing largely depends on the quality of the baseband filter, in our experiment, a 4.7 GHz spacing was necessary. Further reduction in channel spacing resulted in a sharp degradation of BER. Further improvement of bandwidth efficiency can be made using microwave SSB modulation

Owing to the relative low data rates carried by each individual SCM channel, the SCM system can tolerate more dispersion than a TDM system of same capacity. We have made an experimental comparison of the system performance between an OC-192 TDM system and a 4-channel OC-48 SCM system. Fig. 6 shows the measured receiver sensitivities versus the accumulated dispersion. At back-to-back, the sensitivity of SCM system is about 6 dB worse compared to its TDM counterpart because of small modulation index in the SCM system. However, with the accumulated dispersion of higher than 1700ps/nm (corresponds to 100km of SMF), the performance of the TDM system deteriorates rapidly, while the performance of the SCM system remains unchanged. Computer simulations reveal that, an SCM system with 2.5 Gb/s per SCM channel can tolerate up to 8500 ps/nm of accumulated dispersion (equivalent to 500 km of SMF).

In conclusion, we have demonstrated a four-channel digital SCM system with the aggregated capacity of 10Gb/s. Optical SSB modulation allows the system to be able to tolerate large amounts of dispersions and increases the efficiency of optical bandwidth utilization. The minimum of 4.7GHz channel spacing was found to be feasible with commercially available electrical filters.

Acknowledgement

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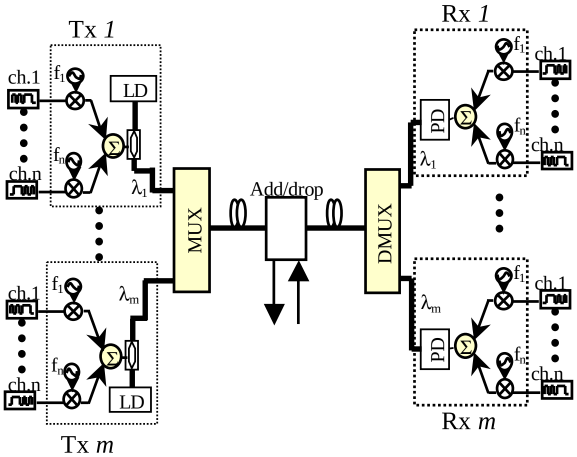

Fig.1, SCM/WDM system architecture

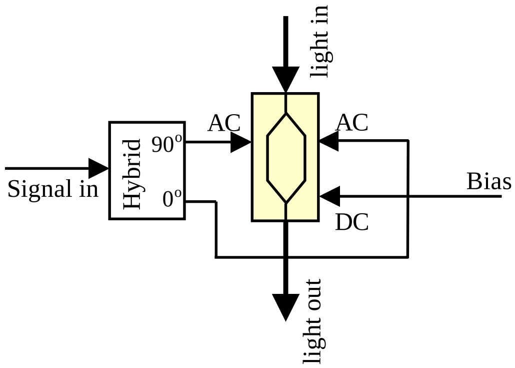

Fig.2, Optical SSB modulation

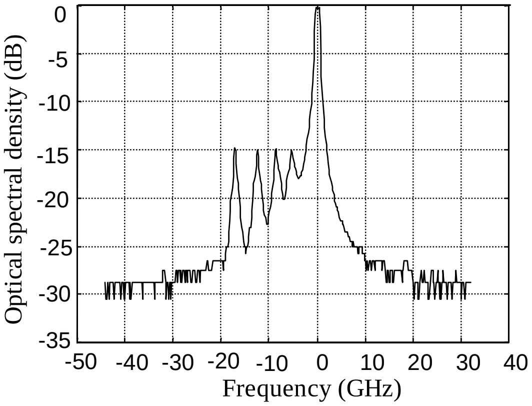

Fig.3, Measured SSB optical spectrum

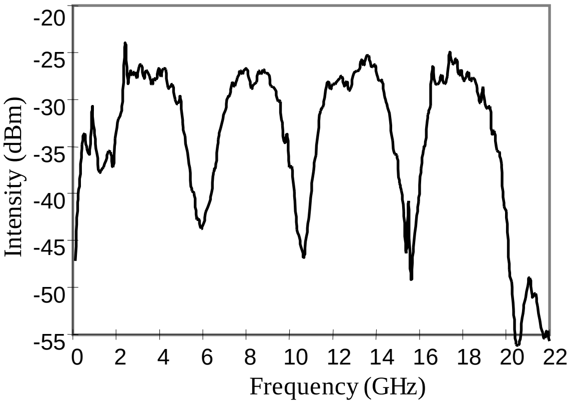

Fig.4, Detected composite signal RF spectrum

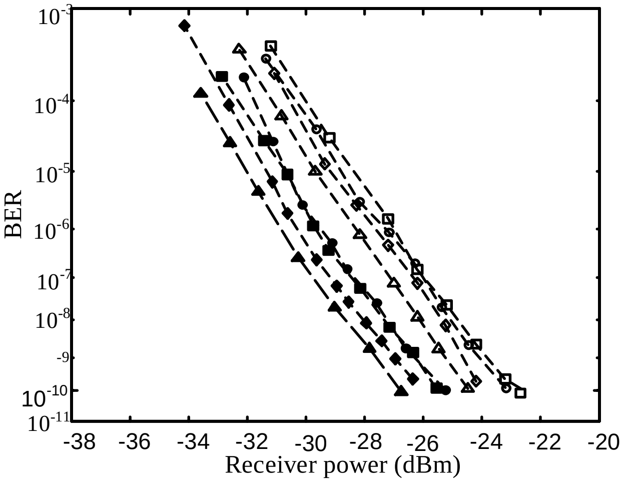

Fig.5, Measured BER before (solid points) and after (open points) transmission.

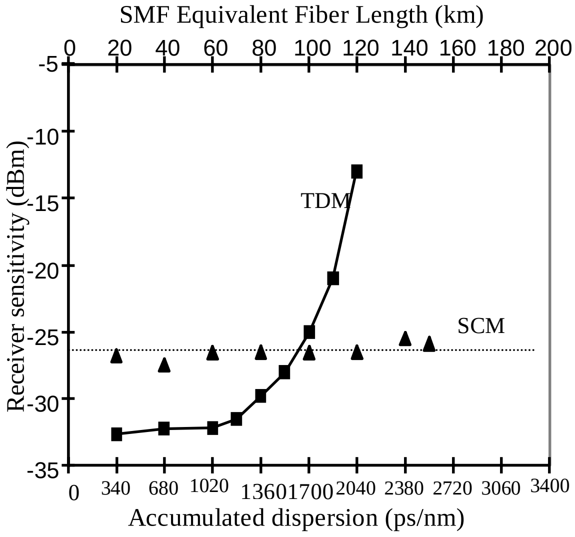

Fig.6, Sensitivity comparison between 10Gb/s TDM (squares) and 10Gb/s SCM (triangles) systems, no dispersion

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