PREFACE

With exploding data transmission traffic occurring every year, we are compelled to raise the bandwidth of communication networks. When this happens, the application of optical technologies does not have an alternative because of the unique transmission capacity or large bandwidth of optical fibers. Optical communication systems have been used since the 1970s for high-volume data transmission within wide-area, metropolitan-area and local-area networks, and its development has been rapid. The introduction of wavelength division multiplexing (WDM) technology increased the capacity of fiber by many folds and this quantum jump enabled a dramatic worldwide increase in Internet usage. Recently, the research target is directed towards higher spectral efficiency, since ultra dense wavelength-division-multiplexing (DWDM) transmission is the key to cost-effective capacity expansion in optical communication systems with a finite bandwidth. Today's accessible throughput of a single fiber is 2 Tb/s, which allows accommodating all telephone traffic of a planet through a single optical fiber. In laboratory conditions it was possible to reach the information transfer speed of 10 Tb/s, and the theoretical maximum is estimated about 300 Tb/s. In addition, the optical fiber has the following advantages: i) Low transmission loss (0.15 to 0.2dB/km), allowing longer repeater spacing and reducing outside plant expense. By comparison, the loss reaches 200 dB/km at 100 MHz for twisted-pair cables and 500 dB/km at 1 GHz for low-cost coaxial cables. Also wireless propagation with carrier frequencies of several giga-hertz incurs an attenuation of tens of decibels across a few meters while supporting data rates of lower than 100 Mb/s. ii) Absence of mutual influences between optical fibers (for example, no crosstalk). iii) Antijam capability without complex codes and technologies. Optical fibers are immune to electromagnetic interference and can be used in noisy environments.

The seemingly insatiable demand for bandwidth has led to the deployment of optical networks operating at several tens of gigabits per second. Commercial time-division multiplexed systems (TDM) running at 40Gbps are now a reality. Commercial deployment of ultra-high speed optical system depends on the availability of low cost and high performance optical/electronic devices and integrated circuits, which enable manufacturing to meet cost, performance, power and size constraints. However, in modern conditions when doubling of the traffic occurs every year, the demand for communication capacity has outpaced the performance of semiconductor systems, which has doubled every 18 months according to Moore's law. On the other hand, the high inherent bandwidth of optical fibers is just beginning to be exploited. Thus long-term, high-risk and hard-going research is necessary to sustain the growth in information transfer capacity.

A basic optical communication system consists of six parts: (1) a serializer, which converts many low-speed parallel data streams into a high-speed serial data stream; (2) electro-optical transducer (e.g., a laser diode) and the relevant driver, or a laser source and a modulator; (3) a fiber; (4) a photodetector (e.g., photodiode); (5) amplifiers including a transimpedance amplifier (TIA) and a limiting amplifier, which amplifies the photodiode output with low noise and sufficient bandwidth, converting it to a large enough voltage signal; (6) a deserializer. The first thee parts makes a transmitter and the last three parts makes a receiver.

The transmitter entails several issues that manifest themselves at high-speeds and in scaled IC technologies. Since the jitter of the transmitted data is determined primarily by that of the frequency synthesizer, a robust, low-noise design with high antijam capability becomes essential. Furthermore, the design of skew-free multiplexers becomes difficult at high data rates. Another critical challenge arises from the laser driver, which is a circuit that must deliver tens of milli-amperes of current with very short rise/fall times and large voltage swings. Since optical modulator in the transmitting end needs to be driven with a large differential waveform, the modulator driver design becomes more difficult as scaled technologies impose lower supply voltages. The optical components of an optical transmission system, such as the laser diode, the fiber, and the photodiode, introduce their own nonidealities and these defects need close interaction between electronic and optical design. Phenomena and guidelines, such as chirp, dispersion, attenuation and efficiency, play a major role in the overall link budget. The receiver in an optical transmission system also suffers from many problems. The noise, gain, and bandwidth of the TIA and the limiting amplifier directly impact both the sensitivity and the speed of the overall system and these specifications will present additional problems as the supply voltage scales down. Moreover, the clock and data recovery (CDR) circuits must satisfy severe jitter and bandwidth requirements and provide a capability of tolerance of long runs, which is a sequence of identical bits.

Full integration of the transceiver on a single chip is another challenge raising a number of concerns. The area saving coming from full integration could be at the expense of circuit performance. For example, when analog front-end circuits are integrated with high-speed digital parts, such as multiplexer and de multiplexer in a low cost CMOS process, the performance of the sensitive circuits will suffer from high switching noise through substrate coupling. The above issues have resulted in multi-chip solutions that integrate the noisy and sensitive functions on different substrates. Recent work has integrated the serializer and deserializer (namely a "SERDES") in a single chip, but the TX and RX amplifiers may remain in isolation. At high speeds and/or high port densities, the power dissipation of optical transceivers becomes critical as it determines the type and size of the package in which the entire module is housed. Integrating a complete SERDES on a single CMOS chip serves as the first step toward much greater intricacy in optical communication transceiver design, and there are still considerable challenges for designers to achieve full integration. In particular, when it comes to full integration, power and area reduction, and noise isolation are the hot topics.

On the whole, increasing the transmission capacity of optical communication systems will require many breakthroughs in research. Novel tunable lasers and amplifiers, high-speed modulators operating between 1200nm-1700nm will need to be devised to open up wider fiber bandwidth. Adaptive devices such as filters, gain and power controllers, and dispersion compensators become increasingly important, as they must be used to overcome the nonideal effects which are no longer possible to neglect at ultra-high transmission speed. Achieving full integration and packaging remain a challenge for broadband optical communications systems with the increasing complexity, scale and further demand for low-cost, high-volume manufacturing, which is crucial to meet the requirement of last-mile applications. These expected targets are obtained as higher level of integration is achieved and new design ideology and fabrication technology are devised.

The design of high-speed optical devices and integrated circuits for optical transceivers and links oriented to low power, low cost and small area will be discussed in this special issue. In addition, other relevant technologies of optical transceivers will also be introduced.

Laser is a key component for optical communication systems. Many techniques, such as soliton dispersion management techniques for novel transmission systems at 40 Gb/s/channel and higher bit rates, rely on clean optical pulses and thus benefit greatly from the availability of simple, compact, low-noise and efficient optical pulse generating lasers. Lasers are becoming increasingly important for telecommunication applications as data transmission rates continue to increase. Gabriel Spuehler and his coworkers reported their new efforts to develope various novel multi-GHz laser sources and their application in optical communication field, such as in the optical time-division multiplexing (OTDM) and DWDM systems. Optical modulator in the transmitting end needs to be driven with a large differential waveform. The design of the modulator driver presents some unique challenge due to the high speeds and high voltage swings involved. Shanthi Pavan et al. discussed design considerations for high-speed high-swing integrated differential modulator drivers in SiGe technology.

Due to the cost consideration, it is a challenge to effectively make use of the huge installed fiber in higher speed optical communication systems without degrading the repeater spacing and transport span between the nodes. This presents a significant challenge because 10Gb/s signals are much more susceptible to the impairments introduced by the installed fiber, such as inter symbol interference (ISI). ISI is a fundamental problem in a digital communication system such as Ethernets and optical backplanes. For a given data rate, the ISI limits the achievable link distance without the optical repeater, due to the fact that the ISI increases exponentially with the transmission distance. Any further increase in the data rate would imply shorter distances. Then, there is a trade off between the data rate and the transmission distance without optical repeater. The main source of ISI is signal pulse broadening due to fiber dispersion. In order to mitigate the effects of dispersion, different methods have been proposed and implemented in the three parts of an optical link span, i.e. transmitter, fiber and receiver, and in both optical and electrical domain. Although the compensation methods can be achieved in optical domain, electrical schemes, in particular equalizer, have attracted a more considerable amount of interest because they allow greater integration with existing circuitry, leading to more compact, less expensive and more adaptive solutions. This is especially true for WDM systems, in which every channel needs dispersion compensation. Several techniques to alleviate dispersion are introduced in this special issue. Prof. Manfred Berroth and Rui Tao designed a monolithically integrated duobinary optical transmitter, which adopts duobinary coding technology as a dispersion compensation method due to its higher spectral efficiency. A 10Gb/s analog continuous-time equalizer with integrated clock and data recovery circuit was presented by Douglas S. McPherson and coworkers and it can be used to recover signals degraded by chromatic and polarization mode dispersion effectively. Jonathan Sewter and Anthony Chan Carusone give a unique and detailed analysis of polarization-mode dispersion (PMD) effects in a 40-Gb/s optical system and the analysis results are used to compare different electronic equalizer architectures as potential PMD compensators. Hence, an increase in maximum transmission length of more than several times or in higher system transmission capacity is achieved.

Serial inputs and outputs (IOs) are widely used in optical communication systems to achieve high-speed data transmission. A key performance for high-speed serial IOs in optical backplane transceivers is the jitter characteristic. Clock and data recovery (CDR) circuit is a crucial component for the jitter characteristic of an optical serial transceiver. Hence, CDR circuits must satisfy stringent specifications defined by optical standards and this presents challenges to system and circuit designers. Although several ways exist to perform clock recovery, for example based on non-linear processing and surface acoustic wave (SAW) filters, monolithic implementations are usually based on a phase locked loop (PLL). Shenggao Li provided an overview of high-speed serial IO design trade-offs over a wide scope ranging from system partitioning, architecture selection, to circuit design techniques, with emphasis on jitter reduction, power and cost saving. Cicero S. Vaucher et al. gave a unique and detailed engineering presentation on the subject of high performance architectures and building blocks for clock and data recovery (CDR) applications and introduces a parallel CDR architecture for high operation speeds and low-power dissipation.

A novel and useful logic style for high-speed, low-power and mixed-signal integrated circuits applications was presented by Yuyu Liu and her coworkers, which is called MOS Current Mode Logic (MCML). MCML circuits seem to be very increasingly popular in the design field of optical transcerivers, such as in designs for gigahertz multiplexer/ demultiplexer and CDR circuits.

Key front-end ICs have been demonstrated in the past using HBT (SiGe, InP, GaAs) and HEMT (InP, GaAs) technologies. Among them InP double hetero-junction bipolar transistor (DHBT) technology exhibits excellent high-speed performance, high breakdown voltage, large-scale integration, good uniformity and reliability. This makes them suitable for realizing both broadband analog amplifiers and large-scale digital circuits required for the optical transceiver components in 40Gb/s or higher speed systems. Kiyoshi Ishii et al. presented their InP-based heterojunction bipolar transistor (HBT) technologies and relevant circuit design techniques, attractive for fabricating ultrahigh-speed integrated circuits for 40 to 100 Gbit/s-class optical communications systems.

From the point of the whole system, a TDM system transceiver with 4–channel 10 Gb/s interfaces to achieve 40 Gb/s non-return to zero (NRZ) optical transmission was presented by Karthikeyan Krishnamurthy et al. Haruhiko Ichino and his coworkers implemented an XENPAK optical transceiver with inter-frame ling signaling (ILS) interface technology to provide a new seamless connection technology between an optical transport network, such as SDH/SONET, and a 10-Gigabit Ethernet. The ILS interface technology is expected to play an important role in achieving highly reliable and cost-effective Ethernet native optical WANs in the future.

In conclusion, new optical communication technologies catering to various system requirements continue to shrive, with the ultimate goal of cramming more information onto relatively limited channels of limited bandwidth using minimum power.

The editors would like to express great gratitude to all the authors for their outstanding contributions to this special issue of "SPECIAL ISSUE ON HIGH-SPEED OPTICAL TRANSCEIVERS: INTEGRATED CIRCUITS DESIGN & OPTICAL DEVICES TECHNIQUE". The Special Issue will prove useful for a large audience: from practicing engineers and scientists to graduate students, who are interested in the development of integrated circuits and devices technology for optical communication applications.

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