Photonic integrated transceivers for data read-out systems

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Abstract: In this work design and characterization results of integrated optical transceivers are presented. The devices were realized as photonic integrated circuits in a generic InP-based technology. The application is a data read-out unit for a sensor network. The circuits utilize PIN photodiodes for detection of a slow speed signal and amplitude modulators, either in a Michelson or a Mach-Zehnder interferometer configuration, for data encoding. Modulation bandwidth of 16.1 GHz was measured, eye-diagrams with 11.6 dB dynamic extinction ratio were recorded and transmission of a 10 Gb/s signal over 25 km of SMF fiber with BER below $10^{-10}$ was achieved.

Introduction

In a distributed sensor network, the read-out system is responsible for collecting all signals generated by a large number of sensors. The system we consider here has a star topology and comprises microelectronic and optoelectronic devices located next to the sensors, and is connected with optical fibers to a central station (CS). The upstream signal, towards the CS, provides information about the monitored physical parameters, while the downstream from the CS may be used for sending a control signal to the sensor units. Figure 1 presents a scheme of an optical link between the central station and a single sensor, where the downstream is a 1.25 Gb/s digital signal, modulated with low extinction ratio (ER = 0.4 dB). At the sensor unit a fraction of the input power is tapped and the downstream signal is detected. The remaining signal is used as a carrier for modulation with high extinction ratio in order to generate the upstream signal. It is assumed that the read-out from the sensor as well as driving the modulators is performed by electronic circuitry deployed at the sensor unit.

![Fig. 1. Optical fiber link between the central station (CS) and a single sensor (left) transceiver circuit schemes in transmitting (a) and reflecting (b) configurations (right)](image)

This concept, based on discrete photonic components, has been proposed and investigated by the Dutch institute for subatomic physics (Nikhef) for the data read-out system of the KM3NeT neutrino telescope experiment\textsuperscript{1}. It utilized a 5%:95% fiber-optic power coupler, a PIN photodiode and a reflective electro-absorption modulator. In this work we demonstrate photonic integrated circuits that combine all of the functionality in a single semiconductor chip. We utilized an InP-based generic integration technology platform\textsuperscript{3}. It supports building blocks such as passive waveguides, electro-optic phase modulators exploiting the quantum confined Stark effect\textsuperscript{1}, PIN photodiodes and semiconductor optical amplifiers.

Chip design

Figure 1 presents the block diagrams of the designed circuits. Two possible arrangements are presented. Both of them utilize a power tap, which is either a symmetric 50%:50% 1x2 MMI power splitter or a 15%:85% 2x2 MMI power coupler, and a PIN photodiode for monitoring the downstream signal. The data from the sensor is encoded onto the carrier using amplitude modulators in either
transmissive Mach-Zehnder (MZM) or reflective Michelson (MM) configuration, constructed from MMI couplers and phase modulators. Additionally, the transmitting circuits utilize a semiconductor optical amplifier in order to boost the power of the output signal. Figure 2 presents the mask layout of the transmitting circuits with two additional test circuits and a picture of a fabricated device mounted on a ceramic block for RF characterization. The chip dimensions are 6x2 mm$^2$.

**Characterization results**

For the RF measurements the chips were mounted on ceramic submounts and the circuit components were wire-bonded to the gold DC pads and RF ground-signal-ground (G-S-G) coplanar transmission lines. The RF-response of the modulators was measured with a 67 GHz lightwave component analyzer (LCA, Agilent N4373C) by injecting CW laser light at 1550 nm and analyzing the modulated signal by the LCA. Figure 3 presents the characteristics of the $S_{21}$ magnitude, normalized at 0 GHz, for the Mach-Zehnder and Michelson type modulators. The measured 3 dB bandwidth is 11.5 GHz and 16.1 GHz, respectively.

![Characterization results](image)

The measured static extinction ratio of the Mach-Zehnder modulators is 18 dB at $\lambda = 1550$ nm and the driving voltage $V_\pi = -3.9$ V. For the Michelson arrangement the ER is 25 dB and $V_\pi = -3.0$ V. Dynamic measurements were performed with the injected CW carrier at $\lambda = 1550$ nm and a pseudo random bit sequence generator which was driving the modulators. The recorded eye-diagrams for the back-to-back configuration are presented in Figure 3 for both types of modulators. In both cases the eye is wide open with the dynamic extinction ratio 11.6 dB and 11.2 dB, respectively. For the Mach-Zehnder circuits transmission of the modulated signal for back-to-back and over 25 km of SMF fiber was achieved with a bit error rate smaller than $10^{-10}$ (measured with Anritsu MP1764C error detector).

**Conclusions**

The integrated optical transceivers were designed and fabricated in a standardized generic InP technology. Their overall performance is good in terms of dynamic extinction ratio higher than 10 dB and available RF bandwidth up to 16 GHz.

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**References**