128 GBaud Coherent Receiver Engine with Flat Frequency Response

Jonas Gläsel[1], Alexander Schindler[2], Hendrik Boerma[1], Thanh T. Tran[1], Felix Ganzer[1], Duy P. Nguyen[3], Billy Allen[3], Patrick Runge[1], Martin Schell[1,2]
[1]Fraunhofer Heinrich-Hertz-Institute, Einsteinufer 37, 10587 Berlin, Germany[1]
[2]Technical University Berlin, 10623 Berlin, Germany
[3]MACOM Technology Solutions, Santa Clara, CA 95050, USA
jonas.glaesel@hhi.fraunhofer.de

Abstract: We demonstrate a high responsivity intradyne coherent receiver engine with 80 GHz bandwidth. A co-design of the InP waveguide integrated coherent photodetector and the dual linear SiGe transimpedance amplifier results in a flat frequency response. A system evaluation at 128 GBaud shows the capability for QPSK and 16QAM.

1. Introduction

Recent publications show a growing interest in high data rate transmission experiments for the development of next generation data center and long-haul communication systems [1, 2]. Therefore, high-speed optoelectronic components like modulators and detectors have been introduced [3, 4]. Compared to direct detection, coherent optical communication systems enable an efficient increase in data rates by employing higher order modulation formats. The use of high symbol rates is beneficial in terms of cost and power efficiency to achieve high data rates but also results in high bandwidth requirements on component level. Component bandwidths of approximately 70 GHz will be needed for 128 GBaud transmission systems.

Coherent photodetectors for the high-symbol rates have been developed mainly based on InP [5, 6]. The superior trade-off between the external responsivity and bandwidth [7] and the possibility of monolithic integration of the local oscillator [8] are advantages in InP compared to Silicon Photonics [9, 10]. For high-performance transimpedance amplifiers (TIAs), SiGe has been a widely recognized technology of choice due to its high-speed and high-gain capabilities. [11]. Here, we propose hybrid integration of an InP PIC with mature SiGe TIAs, which allows for combining the aforementioned strengths in terms of high-performance. We are convinced that the additional die attach and bonding costs are negligible in volume production.

In this contribution, we demonstrate a high responsivity 80 GHz-bandwidth intradyne coherent receiver (ICR) engine with flat frequency response for 128 GBaud applications. A first system evaluation is performed.

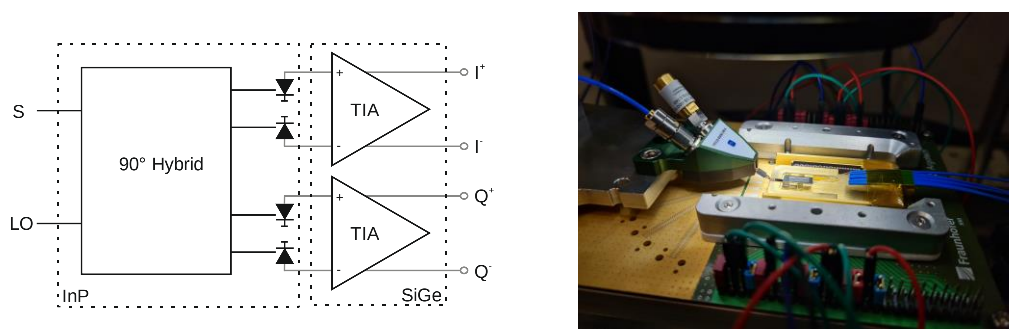


Fig. 1. Receiver engine schematic consisting of an InP PIC including a 90° hybrid and four photodetectors and the dual linear SiGe TIA MMIC (left) RF measurement setup of the ICR subassembly (right)

2. Design, Fabrication and Assembly

InP photodetectors according to Fig. 1 (left) have been fabricated on HHIs InP platform. The fabrication process is described in detail in [5]. To enable 128 GBaud and achieve the best possible performance in combination with the TIA, the photodetector was optimized in terms of responsivity and bandwidth compared to our previous publications. The epitaxial layer stack was adapted to reduce the transit time and RC-limitation of the photodetectors without degrading the responsivity. Furthermore, a sophisticated RF pad design was developed by co-designing the interface between TIA and photodetector with electromagnetic 3D-simulations to reduce RF transmission losses and suppress higher order mode propagation. In a next step, the coherent photodetector and the TIA were assembled in a butterfly package to ensure robust optical coupling and to allow convenient DC connections using a suitable evaluation board (Fig. 1 right).

3. Measurement Results

The coherent photodetector was characterised with a PD reverse bias voltage of 2 V, using TE polarized light at the input. Fig. 2 (left) shows the photodetector external responsivity of > 0.125 A/W over the entire C-band for signal (S), and the local oscillator (LO) input. In Fig. 2 (right) the intra phase error is presented, being less than ±2° over the whole C-band.

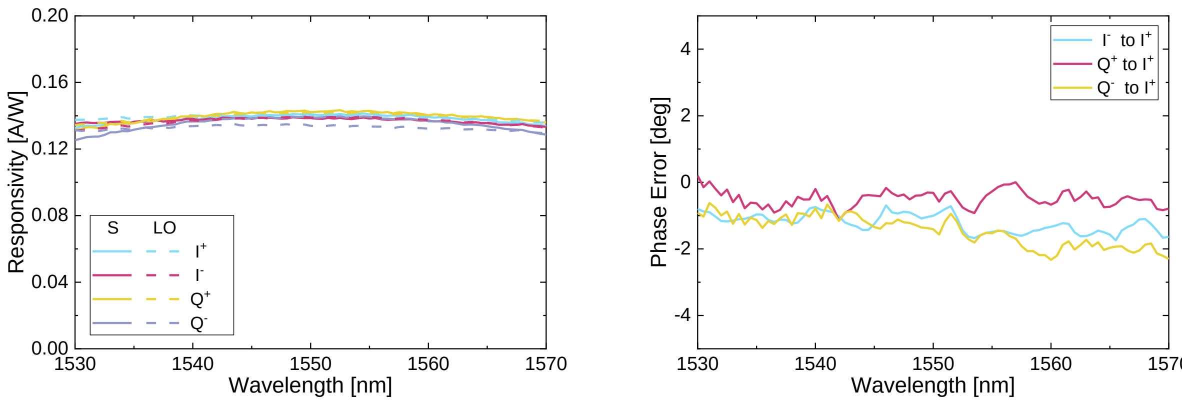


Fig. 2. Responsivity (left) and phase error (right) measurements in dependence of the wavelength of the photodetector chip for TE polarization

Furthermore, the optical/electrical frequency response of the receiver engine subassembly (incl. coherent photodetector and TIA) was measured using a heterodyne setup and a dual channel RF-probe with 1 mm connector (Fig. 1 right). Fig. 3 (left) shows the measurement results. A -3 dB-bandwidth of 80 GHz was measured at 0.8 mA photocurrent while maintaining a flat frequency response with a maximum peaking of around 2 dB. A flat frequency response is essential to avoid ringing effects reducing the extinction ratio of the eye pattern. The I^+/Q^+ and the I^-/Q^- channel were measured consecutively while one probe channel was terminated by 50 Ω respectively. Moreover, the RF common mode rejection ratio (CMRR) can be calculated from the measurement data accordingly to [5]. A RF CMRR of less than -20 dB up to 80 GHz is obtained (Fig. 3 right).

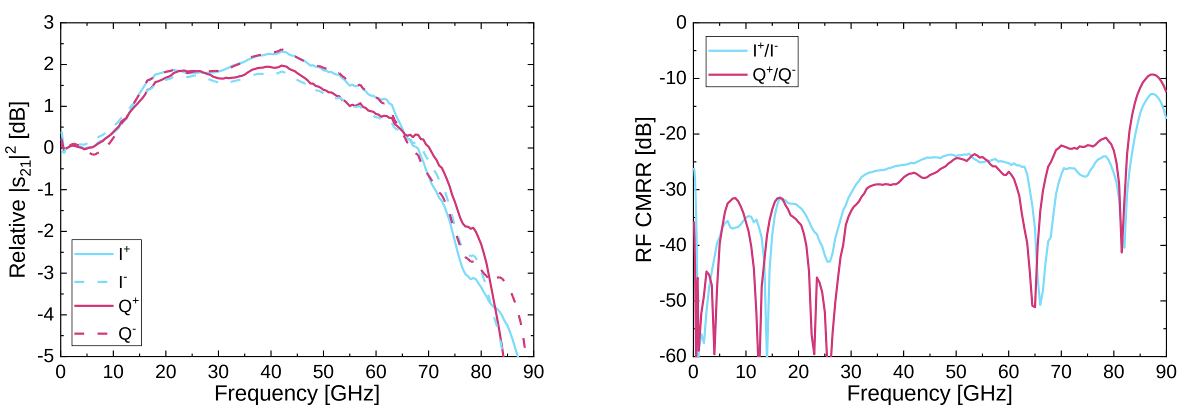
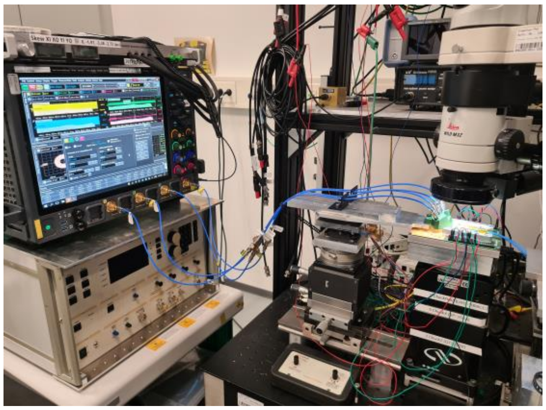


Fig. 3. Frequency response measurements (left) and RF CMRR measurements (right) of the coherent receiver engine subassembly

Subsequently, a system evaluation with the ICR subassembly was realized. A nominal 8 bit 128 GSa/s digital-analog converter (DAC) with 45 GHz of analog bandwidth in combination with an optical multi-format transmitter (OMFT) was used to generate single polarization (SP) 128 GBaud signals. Further details on the transmitter, the implemented pre-distortion and the coherent transport DSP are provided in [11]. On the receiver side, the ICR was measured using a nominal 10 bit 256 GSa/s real-time oscilloscope with 113 GHz of analog bandwidth in differential mode. However, to establish the connection between the receiver engine and the oscilloscope a RF probe, 80 cm phase matched RF cables, DC-blocks and RF adapters were needed. The attenuation of the RF connection is estimated to 10 dB at 80 GHz. The system measurement setup on the receiver side is shown in Fig. 4 (left). The measured BER in dependence of the optical signal input power at a constant LO power of 10.7 dBm and a fixed TIA gain in a back-to-back configuration at 40 dB of optical signal to noise ratio (OSNR) is shown in Fig. 4 (right). Additionally, the constellation diagrams are depicted at the minimum BER for a signal input power level of -7 dBm. While the transmission with SP-QPSK showed a minimum BER value of 1×10^{-6} the SP-16QAM BER was just below the OpenFEC limit of 2×10^{-2}. The signal degradation can be mainly attributed to the limited 3dB frequencies of the 128GSa/s-transmitter DAC (45 GHz) and the OMFT (55 GHz). At the time of the measurements, no faster transmitter was available. Moreover, the measurement setup on the receiver side can be further optimized by shorter RF cables.



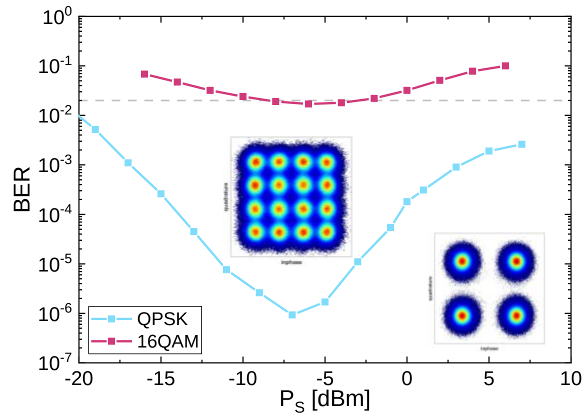


Fig. 4. System measurement setup (left) and system performance at 128 GBaud SP-QPSK and SP-16QAM in dependence of the optical signal input power at 10.7 dBm LO power (right)

4. Conclusion

An 80 GHz-bandwidth ICR subassembly consisting of 0.14 A/W high external responsivity photodetectors and a dual channel linear TIA, suitable for 128 GBaud applications was presented. The excellent performance in terms of responsivity, frequency response flatness, and phase error can compete with state of the art devices [6, 8]. The devices are an important step towards next generation data center and long-haul optical communication systems. We are convinced that a faster transmitter for the system evaluation will result in significantly lower BER values at 128 GBaud 16QAM. Results on that will be presented at the conference.

5. Acknowledgement

We thank Robert Emmerich and Colja Schubert from Fraunhofer HHI's Photonic Networks department for their support. This work was partly funded by the EU Horizon 2020 Project FLEX-SCALE under grant 101096909.

References

[1] H. Mardoyan et al., "First 260-GBd Single-Carrier Coherent Transmission over 100 km Distance Based on Novel Arbitrary Waveform Generator and Thin-Film Lithium Niobate I/Q Modulator", 2022 European Conference on Optical Communication (ECOC 2022), Basel, Switzerland, 2022 pp. 1–4.
[2] J. Manuel Estaran et al., "140/180/204-Gbaud OOK Transceiver for Inter- and Intra-Data Center Connectivity," J. Lightwave Technol., vol. 37, no. 1, pp. 178-187, 2019.
[3] P. Runge et al., "Broadband 145GHz Photodetector Module Targeting 200GBaud Applications," 2020 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2020, pp. 1-3.
[4] J. Ozaki et al., "Over-85-GHz-Bandwidth InP-Based Coherent Driver Modulator Capable of 1-Tb/s/λ-Class Operation", J. Lightwave Technol., vol. 41, no. 11, pp. 3290-3296, 2023.
[5] P. Runge et al., "Polarisation insensitive coherent receiver PIC for 100Gbaud communication," 2016 Optical Fiber Communications Conference and Exhibition (OFC), Anaheim, CA, USA, 2016, pp. 1-3.
[6] T. Okimoto et al., "80-GHz Bandwidth and High Responsivity of InP Coherent Receiver PIC with Butt-joint waveguide PDs," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2023, pp. 1-3.
[7] T. Beckerwerth et al., "High-Speed Photodiodes for Power Efficient Data Transmission," J. Lightwave Technol., early access, 2023 doi: 10.1109/JLT.2023.3322467.
[8] S. Porto et al., "Demonstration of a 2 x 800 Gb/s/wave Coherent Optical Engine Based on an InP Monolithic PIC", J. Lightwave Technol., vol. 40, no. 3, pp. 664–670, 2022.
[9] A. H. Ahmed et al. "A Dual-Polarization Silicon-Photonic Coherent Receiver Front-End Supporting 528 Gb/s/Wavelength", IEEE J. Solid-State Circuits, vol. 58, no. 8, pp. 2202–2213, 2023.
[10] A. Osman et al. "First 100 Gb/s Monolithically Integrated Electronic-Photonic Coherent Receiver With Direct Edge Coupling to Standard Single Mode Fiber Array" 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2023, pp. 1-3.
[11] A. Awny et al., "A Linear Differential Transimpedance Amplifier for 100Gb/s Integrated Coherent Optical Fiber Receivers," IEEE Trans. Microw. Theory Techn, vol. 66, no. 2, 2018, pp. 973-985.
[12] R. Emmerich et al., "Enabling S-C-L-Band Systems with Standard C-Band Modulator and Coherent Receiver Using Coherent System Identification and Nonlinear Predistortion," J. Lightwave Technol., vol. 40, no. 5, pp. 1360-1368, 2022.