

Detector-On-Demand for Flexible Homodyne Transmission

Bernhard Schrenk⁽¹⁾, and Fotini Karinou⁽²⁾

⁽¹⁾AIT Austrian Institute of Technology, Center for Digital Safety&Security / Security & Communication Technologies, 1210 Vienna, Austria. E-mail address: bernhard.schrenk@ait.ac.at

⁽²⁾Microsoft Research Ltd., 198 Cambridge Science Park, CB4 0GW Cambridgeshire, United Kingdom.

Abstract.

We demonstrate a segmented coherent detector configuration that enables polarization-insensitive or -multiplexed reception in half- or full-duplex operation mode for single- λ or ultra-dense WDM configurations with up to 91 Gb/s/sub- λ OFDM data rate.

1. Introduction

With 6G applications looming on the horizon, the metro segment is expected to support Tb/s capacities through a flexible and reconfigurable network [1]. As a prime notion in such optical networks, an adaptation to the highly dynamic bandwidth demand or channel loss, both in terms of a reconfigurable spectral allocation [2-4] or expansion towards the space and polarization dimensions [5], is deeply rooted in the layouts of modern optical transmission systems. Ideally, this goal is accomplished by optical transponders without physically altering or over-provisioning its optical-layer configuration during the lifecycle, calling in return for a very flexible optical transceiver engine.

Towards this direction, we have proven an electro-absorption modulated laser (EML) as full-duplex coherent homodyne transceiver [6]. Here, we expand on these findings by introducing a segmented EAM configuration for low-cost, high-capacity coherent OFDM transmission in various scenarios: We experimentally demonstrate a segmented electro-absorption modulator (EAM) detector architecture and show that a flexible assignment of polarization and spectrum and half-/full-duplex operation modes can be supported. Furthermore, access to the sub-DWDM dimension through balanced detection enables a dense channel allocation with 91.6 Gb/s/sub- λ data rates.

2. Coherent Detector-on-Demand and Experimental Setup

The proposed transceiver features a synthesized detector / modulator engine, with the ability to (i) partition RF spectrum towards single- λ full-duplex transmission, (ii) double the capacity through access to the polarization dimension and (iii) accomplish coherent WDM reception to enhance the spectral efficiency.

Configuration	TRX	BW [GHz]	λ	TX pol.
① Half-duplex	DET-1	15 DS	λ_T	TE
② Full-duplex bidi	DET-1	6 DS, 6 US	λ_T	TE
③ Pol. independent	DET-1	15 DS	λ_T	TE scramb.
④ Pol. multiplexed	DET-2	15 DS	λ_T	TE + TM
⑤ Balanced det.	DET-3	15 DS	λ_T	TE
⑥ UDWDM	DET-3	15 DS	$\lambda_T, \lambda_{a1/2}$	TE

Table 1. Detector-on-demand configurations for six scenarios.

Figure 1a presents the experimental setup to evaluate the proposed transceiver (TRX) that will be evaluated in various scenarios (Table 1). It builds on an injection-locked LO with a free-running wavelength of ~ 1550.46 nm and having a locking range of 5.3 GHz for an injection level of -10 dBm, rendering it stable even for low ROP levels and sub-optimal state of input polarization. The multi-purpose detector/modulator EAM has a -3dB bandwidth of 13.6 GHz and is biased at -1.5V. Three segmented configurations are evaluated: a single-ended inline-EAM (DET-1 in Fig. 1b) that either detects [6] or modulates the TE, TM polarizations at its two inputs, a serialized EAM representation (DET-2 in Fig. 1c) that provides dedicated electrical ports for the TE and TM polarizations, and a balanced EAM (DET-3 in Fig. 1d). All these configurations could be realized simultaneously through four EAM sections, so that a definition of the TRX function then occurs at the electrical domain and without change at the optical layer. For example, bidirectional full-duplex operation of DET-1 can be facilitated through slicing the RF spectrum for the EAM through a RF duplexer (DPX). It shall be noted that injection-locked LO provides optical frequency and phase synchronization to the received signal. However, the use of fiber-pigtailed components leads to inevitable phase fluctuations. To mitigate these, we availed of environmental stabilization, a 2-kHz linewidth laser at the head-end (λ_T) and fiber stretchers between the signal and LO paths within the TRX, controlled by feedback on

the detected RF spectrum. The 128 sub-carriers of the single-polarization and polarization-multiplexed OFDM downstream (DS) are adaptively bit loaded. Two closely-spaced adjacent channels ($\lambda_{a,1/2}$) are provisioned at the ITU-channel 34 for the balanced detection case, together with the DS channel λ_T at 1550.47 nm, to which the LO of the TRX unit is optically locked. Polarisation scrambling is applied to investigate polarization-independent TRX operation. A pre-amplified PIN/TIA receiver detects the upstream (US). Figure 1e shows the optical spectra for half-duplex 15-GHz DS reception and the filtering effect when injection-locking the LO. Figure 1f shows the shared spectrum among a full-duplex 6-GHz DS and 6-GHz US.

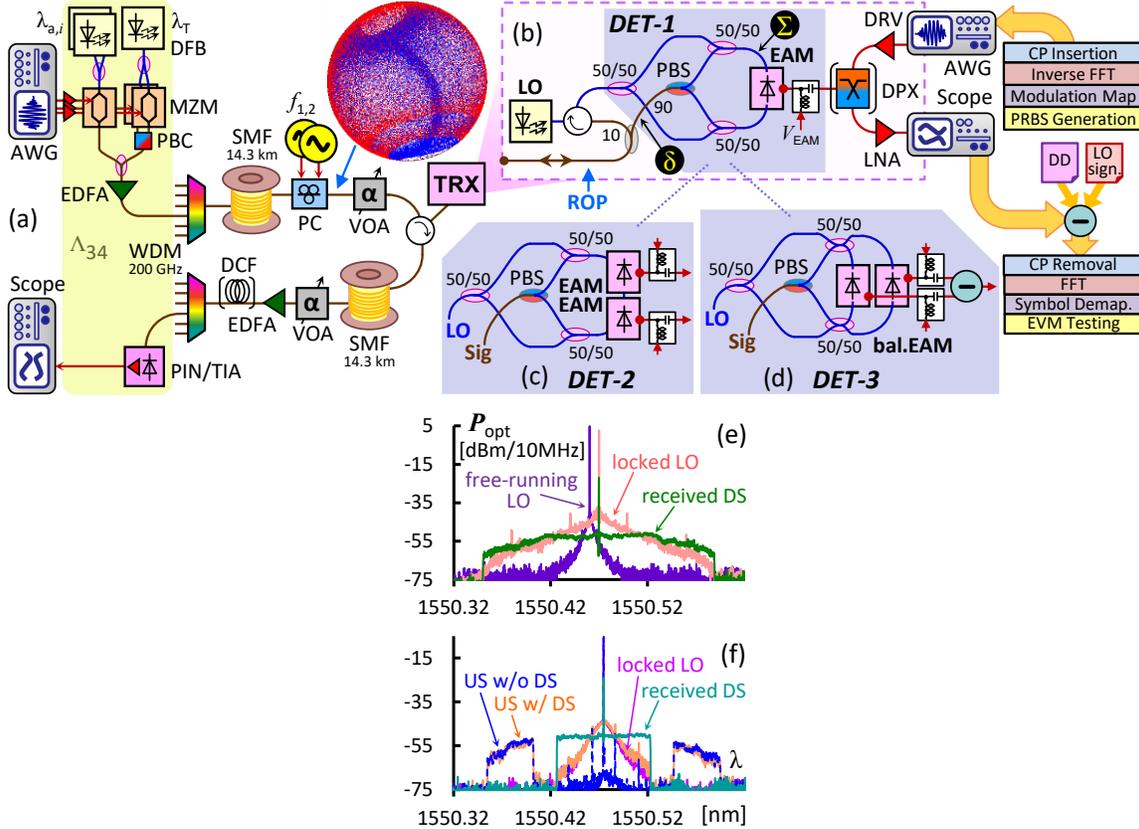


Fig. 1. (a) Experimental setup and detector architectures for (b) single-ended EAM and (c) segmented EAM and (d) balanced EAM detectors. The inset shows the polarization-scrambled DS signal. Optical spectra for (e) half-duplex 15-GHz DS and (f) full-duplex 6-GHz DS/US transmission.

3. Results and Discussion

Figures 2a/b report the RF spectra and EVM for single- λ , single-polarization *half-duplex* back-to-back (b2b) 15-GHz DS reception with *single-ended EAM* detector (DET-1 in Fig. 1b) at a ROP of 1.8 dBm. At this high ROP level, direct-detection (DD) terms are significant and lead to an EVM degradation, resulting in an average modulation efficiency of 2.41 bit/sym (●) for optimized bit loading. When applying a time-synchronized feed-forward cancellation of separately recorded DD terms, the modulation efficiency would improve to 3.28 bit/sym (■). At the same time, residual DS components contaminate the locked LO, especially in a region beyond the injection-locking range. We cancelled this LO signature by feeding forward a respective recording taken after interrupting the DS signal at point δ in Fig. 1b. The modulation efficiency then improves to 3.41 bit/sym (▲), which equates to an OFDM data rate of 47.1 Gb/s. Besides direct OFDM demodulation and additional feed-forward cancellation, which has been applied for the sake of investigating penalties, no further DSP methods were required to accomplish homodyne OFDM reception, as proven through the clean sub-carrier constellations in Fig. 2b.

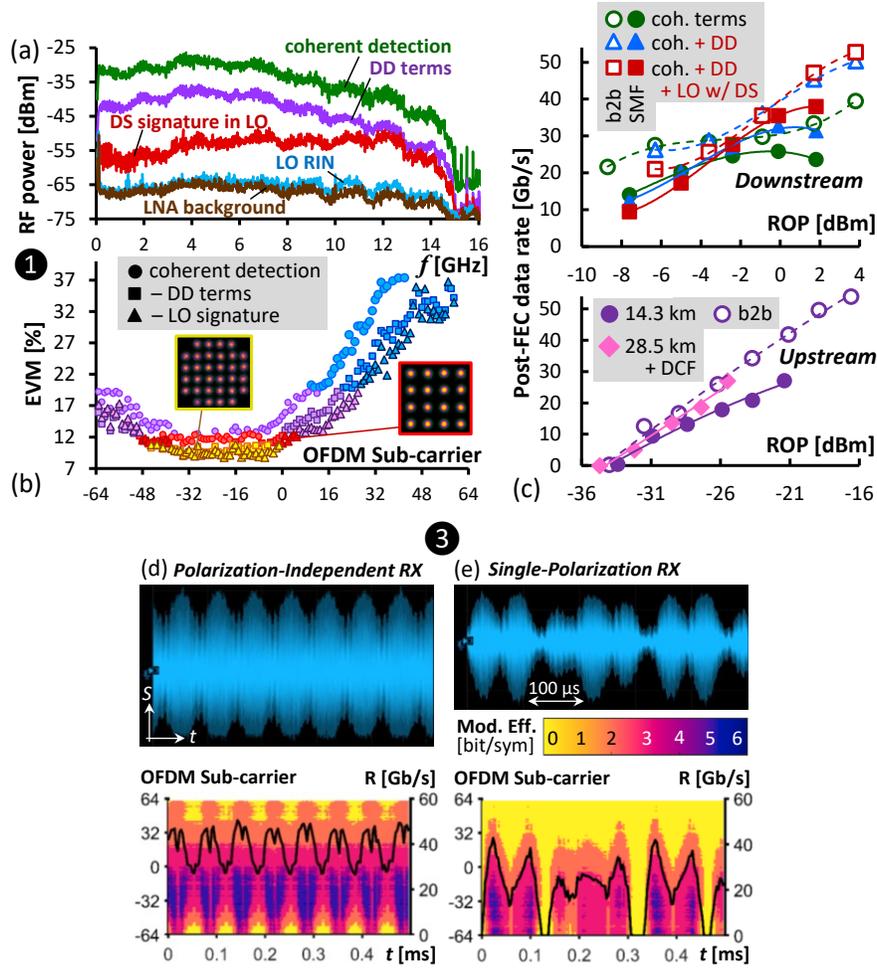


Fig. 2. (a) 15-GHz DS spectra and (b) b2b EVM. (c) OFDM rate vs ROP. (d) Polarization-independent and (e) single-polarization DS reception.

Figure 2c presents the DS performance as a function of the ROP. For b2b transmission, we can identify the single-ended TRX architecture as a limiting factor towards higher ROP (\circ) due to the relatively wide gap to the reception case insensitive to DD-terms (\triangle). For transmission over 14.3 km, the penalty in data rate (\blacksquare, \square) is attributed to chromatic dispersion. Figure 2c further discusses the half-duplex 15-GHz US transmission performance when using the EAM exclusively as transmitter. We obtain an OFDM data rate of 53 Gb/s for a ROP of -17 dBm at the EDFA+PIN based US receiver (\circ). Dispersion-induced fading quickly deteriorates the performance, leading to a $\sim 40\%$ penalty in peak rate for 14.3 km SMF transmission (\bullet). This penalty is due to chromatic dispersion, as proven through a DCF-assisted (-425 ps/nm) US receiver when transmitting over 28.5 km with negligible rate penalty (\blacklozenge).

The *polarization-independent* TRX operation is proven in Fig. 2d for driving the polarization controller (PC) simultaneously at $f_{1,2} = 15$ and 6 kHz. This results in a scrambled polarization state for the received DS (Fig. 1a) during its block-wise OFDM demodulation. While for the polarization-diversity TRX architecture the data rate varies in a range between 26.5 and 50.4 Gb/s, we see an expected drop in modulation efficiency down to 0 bit/sym in case of a single-polarization TRX (Fig. 2e), for which one EAM port has been left disconnected (Σ in Fig. 1b).

Figure 3a presents the RF spectra at the EAM-based DS and EDFA+PIN based US receivers for *full-duplex* b2b DS/US transmission for a DS ROP of -0.5 dBm, together with the transfer function T_{DPX} of the RF duplexer at the TRX. Without US, the received 6-GHz DS features a good EVM performance with a modulation efficiency of 5.23 bit/sym (Fig. 3b, \bullet). This corresponds to a data rate of 29 Gb/s. When activating the US, a crosstalk note can be noticed towards the edge of the DS band of the DPX (Fig. 3a). Still, the crosstalk is bearable even though the US is ~ 5 orders-of-magnitude stronger. In this case of simultaneous US transmission at the upper RF band, the modulation efficiency of the DS drops slightly to 4.93 bit/sym (Fig. 3b, \blacktriangle). An OFDM rate of 27.3 Gb/s is supported. This proves the successful wavelength-sharing of DS and US. The modulation efficiency obtained for US transmission

was 4.82 bit/sym (■) for a ROP of -17 dBm at the EDFA+PIN US receiver, equivalent to a rate of 26.7 Gb/s (Fig. 3c).

Figure 3d summarizes the OFDM rates for DS (▲,■) and US (●,◆) for b2b and fiber transmission. When compared to the half-duplex 6-GHz DS, we see a rate penalty of 9-35% for full-duplex transmission (▲,■) over the entire range of ROP. Due to the reduced signal bandwidth of 6 GHz, there is no additional dispersion-induced penalty. The US performance is widely independent of the presence of DS data. Concerning chromatic dispersion, similar conditions apply as for the half-duplex 15-GHz US transmission (Fig. 2c) since the US is spectrally allocated to the upper RF band.

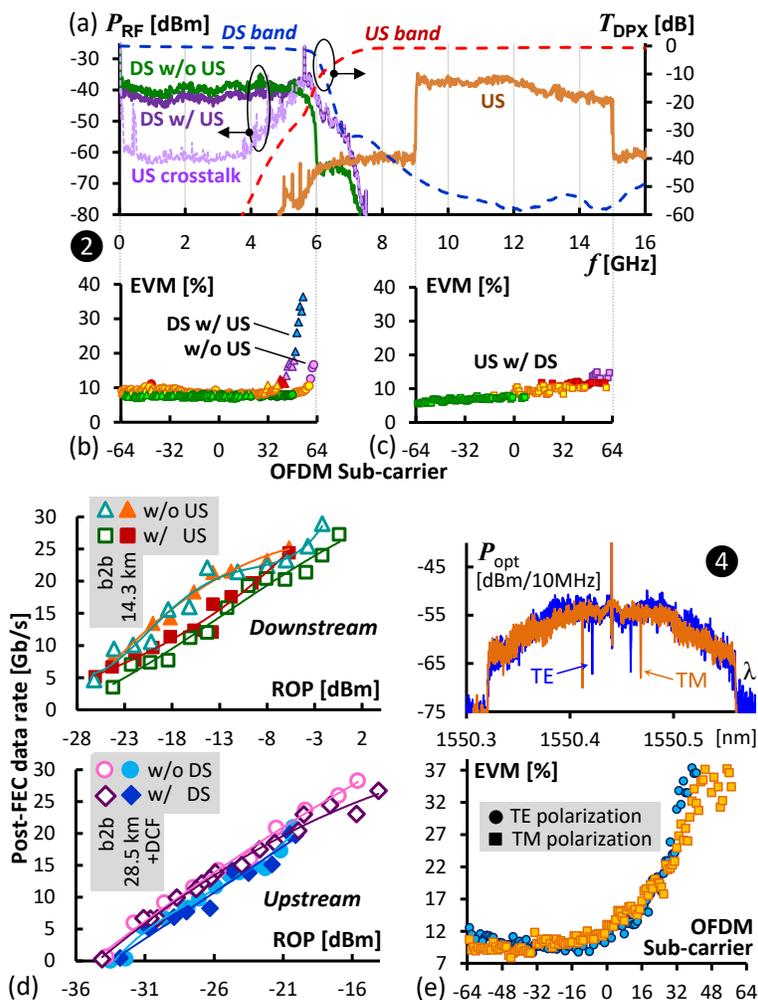


Fig. 3. (a) Full-duplex DS/US RF spectra and EVM for (b) DS and (c) US. (d) OFDM rate vs ROP. (e) Polarization-multiplexed DS reception.

Figure 3e shows *polarisation-multiplexed* reception with the segmented EAM of DET-2 (Fig. 1c). We transmitted two 15-GHz DS signals with a distinctive notch at one OFDM sub-carrier in the TE, TM polarizations and aligned the input polarization to the TRX for optimal separation. The EVM, taken for a ROP of 4 dBm, shows average modulation efficiencies of 3.41 and 3.21 for TE and TM, permitting 91.6 Gb/s reception in total.

Figure 5 proves the *balanced EAM* operation (DET-3 in Fig. 1a) for DS reception in an ultra-dense, 34-GHz spaced WDM scheme within channel Λ_{34} (Fig. 4a). We see an improvement of ~ 14 dB in average for the suppression of DD terms and adjacent channel noise (Fig. 4b). The penalty arising from the adjacent channels $\lambda_{a,1/2}$ (▲ in Fig. 4c) in terms of modulation efficiency can be entirely recovered through the balanced EAM configuration (■), permitting a single-polarization data rate of 58.8 Gb/s for a ROP of 4 dBm, similar to the rate of 62.4 Gb/s obtained for single-channel transmission at λ_T (●) within Λ_{34} . The balanced EAM detector does not require digital compensation concerning DD terms or the DS signature in the LO.

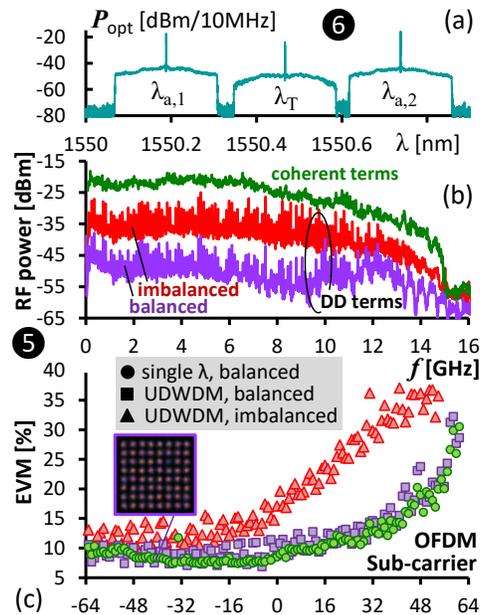


Fig. 4. (a) Optical spectra, (b) DD terms and (c) EVM for balanced EAM detector configuration.

4. Conclusion

We have experimentally evaluated EAM technology to synthesize a multi-purpose modulator/detector for a variety of coherent reception and transmission functions with increased flexibility in the use of optical (λ , polarization) and electrical (RF spectrum) network resources. We have demonstrated polarization-multiplexed, full-duplex and UDWDM modes through such a segmented EAM configuration in combination with a synchronized LO for coherent OFDM reception. Future work will comprise of the photonic integration of the segmented detector.

5. References

- [1] L.S. de Sousa et al., "Metropolitan optical networks: A survey on single-layer architectures" *Opt. Switching and Netw.* **47**, 100719 (2023).
- [2] W. Shieh, "OFDM for Flexible High-Speed Optical Networks," *JLT* **29**, 1560 (2011).
- [3] L. Nadal et al., "SDN-Enabled Multi-Band S-BVT Within Disaggregated Optical Networks," *JLT* **40**, 3479 (2022).
- [4] D. Welch et al., "Digital Subcarrier Multiplexing: Enabling Software-Configurable Optical Networks," *JLT* **41**, 1175 (2023).
- [5] C. Wang et al., "Optical Slicing to Enhance Application Performance over a Metro Transport Network," *Proc. OFC, W4F.5* (2022).
- [6] B. Schrenk, "The Electroabsorption-Modulated Laser as Optical Transmitter and Receiver: Status and Opportunities", *Optoel.* **14**, 374 (2020).

6. Acknowledgement

This work was supported by the ERC under the EU Horizon-2020 programme (grant agreement No 804769).