Enabling 64Gbaud Coherent Optical Transceivers

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Abstract: We establish bandwidth requirements for 64Gbaud coherent transceivers, and show comparisons with commercial device models. Compared to theory, our results suggest OSNR penalties as low as 2.2dB for DP-64QAM and DP-16QAM, and 1.1dB for DP-4QAM.

OCIS codes: (060.1660) Coherent communications; (060.2340) Fiber optics components; (060.4080) Modulation

1. Introduction

The optical transport landscape continues to get redefined by over-the-top service offerings and distinctive product requests from cloud service providers and traditional network operators. While current-generation coherent interfaces employ 32Gbaud per lambda transceivers with up to DP-16QAM modulation – and multiples therein to support 200Gb/s, 400Gb/s and 1Tb/s super-channels –, the upcoming generation of high data rate products also need to address crucial data center interconnect (DCI) requirements of higher capacity, greater faceplate density and lower cost per bit for short reach applications (e.g. 80km).

In addition to increasing bits per symbol and the use of integrated photonics, 64Gbaud coherent transceivers may offer doubled device throughput, w.r.t state-of-the-art systems, adequately addressing aforementioned demands. However, the use of multi-level modulation formats such as dual polarization quadrature amplitude modulation (DP-64QAM) and a higher symbol rate of 64Gbaud are expected to incur significant optical signal-to-noise ratio (OSNR) penalties which need to be understood and minimized for acceptable system operation. Recently, the optical internetworking forum announced the CFP8-ACO project with the aim to develop such transceivers with small form factor, and a target power consumption of 20W [1]. On the other hand, several research groups have demonstrated serial single lambda high symbol rate solutions up to 61Gbaud [2], and DP-128QAM [3]. Electrical time division multiplexed solutions have also been proposed for higher symbol rate transmission [4], however, serial digital-to-analog converter (DAC) based solutions are preferable due to its inherent flexibility. Nevertheless, in order to move the higher symbol rates into products a systematic analysis is needed on component specifications and corresponding system-level performance penalties. Furthermore, as optoelectronics components dominate the costs of coherent modems, part of the component complexity needs to be relaxed with the aid of powerful coherent digital signal processing (DSP) algorithms, enabling such solutions to move into cost sensitive market segments.

In this paper, we establish bandwidth requirements for the entire signal path, including DAC, driver, Mach Zehnder modulator (MZM), optical frontend (OFE) and analog-to-digital converter (ADC), considering 64Gbaud DP-64QAM, DP-16QAM and DP-4QAM. Our results confirm that 64Gbaud coherent transceivers only necessitate a modest increase in required component bandwidths, compared to currently commercial optoelectronic devices – in line with recent supplier announcements [5]. In particular, we show that while current generation components may incur a worst-case OSNR penalty (at a BER of 10^{-2}) of 7.7dB for 64Gbaud DP-64QAM, next-generation components based on DP-64QAM bandwidth requirements may reduce such penalties to 2.2dB, whereas, even components based on DP-4QAM requirements only incur 3dB maximum penalty. Furthermore, in the absence of digital pre-emphasis (DPE), OSNR penalties for 64Gbaud coherent modems are reported to be prohibitively high.

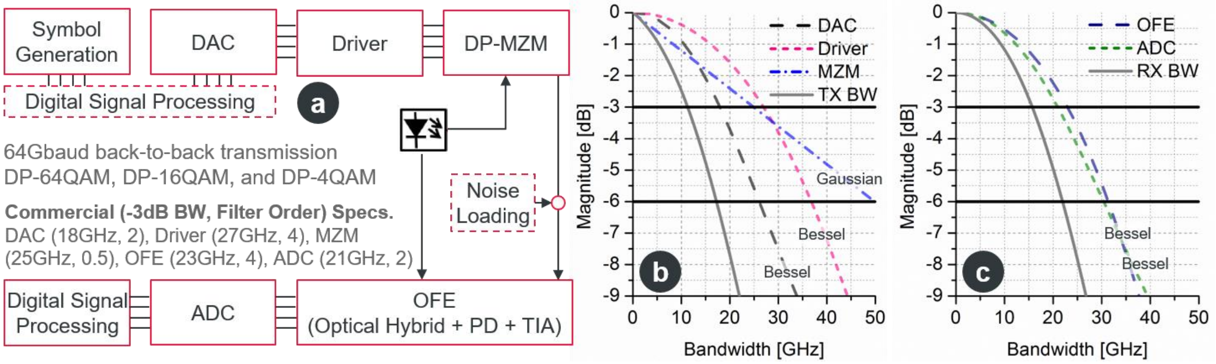


Fig. 1: a) Back-to-back simulation setup, b) & c) Typical S21 response models based on experimental measurements of various current commercial transceiver components.

2. Simulation setup

Fig. 1a shows the simulation setup, where pseudo-random-bit-sequences (2^{18}) were mapped to 64QAM, 16QAM or 4QAM constellations, and 2.5% training overhead was added. The DSP prior to DAC (6 effective bits at 128GS/s) included root-raised-cosine pulse shaping (roll-off factor of 0.2), and – optionally – digital pre-emphasis [6]. The signals were then amplified using driver amplifiers, and fed, together with a 100kHz laser (1550nm), to the in-phase quadrature-phase modulators per polarization, resulting in 64Gbaud DP-QAM signals. At the receiver, noise loading was performed to enable OSNR sweeps, followed by coherent detection, employing 90° hybrid, photodiodes and TIAs at the frontend. The signals were then digitized using a 6 effective bit ADC at 128GS/s. Finally, DSP was performed using conventional stages [3], and bit error rate (BER) count over 200k symbols.

Fig. 1b and Fig. 1c. show the S21 responses for the entire transceiver chain, modeling current commercial bandwidth specifications, and experimentally measured component responses. The total transmitter and receiver -3dB bandwidth is 11.5GHz and 15.5GHz, respectively. Note that while the -3dB bandwidth is the typically reported specification, S21 roll off is also a critical design parameter, captured by the -6dB bandwidth in presented curves.

3. Results and discussions

Fig. 2 depicts bandwidth requirements for DAC, Driver, MZM, OFE and ADC individually, employing 64Gbaud DP-64QAM (Fig. 2a), DP-16QAM (Fig. 2b), and DP-4QAM (Fig. 2c), at received OSNRs of 29.6dB, 23.6dB and 16.9dB, respectively. The bandwidth of the component under test is varied, while all other systems specifications are kept at current commercial values, as mentioned in the previous section. With this approach one can observe the practical impact of a higher bandwidth device plugged into today's subsystems. In general, it can be seen that transmit-side components have higher bandwidth requirements compared to receiver-side devices. More specifically, the DAC requires the highest bandwidth to enable 64Gbaud transmission, and tends to crossover driver limitation due to its less steep roll off, compared to the driver amplifier, however, this trend only becomes visible at higher penalties. Likewise, while the MZM response only falls off gradually (see Fig. 1b), a substantive advantage may only be gained at relatively higher penalty points. Furthermore, it can also be seen that the component bandwidth requirements tend to converge as bits per symbol are decreased.

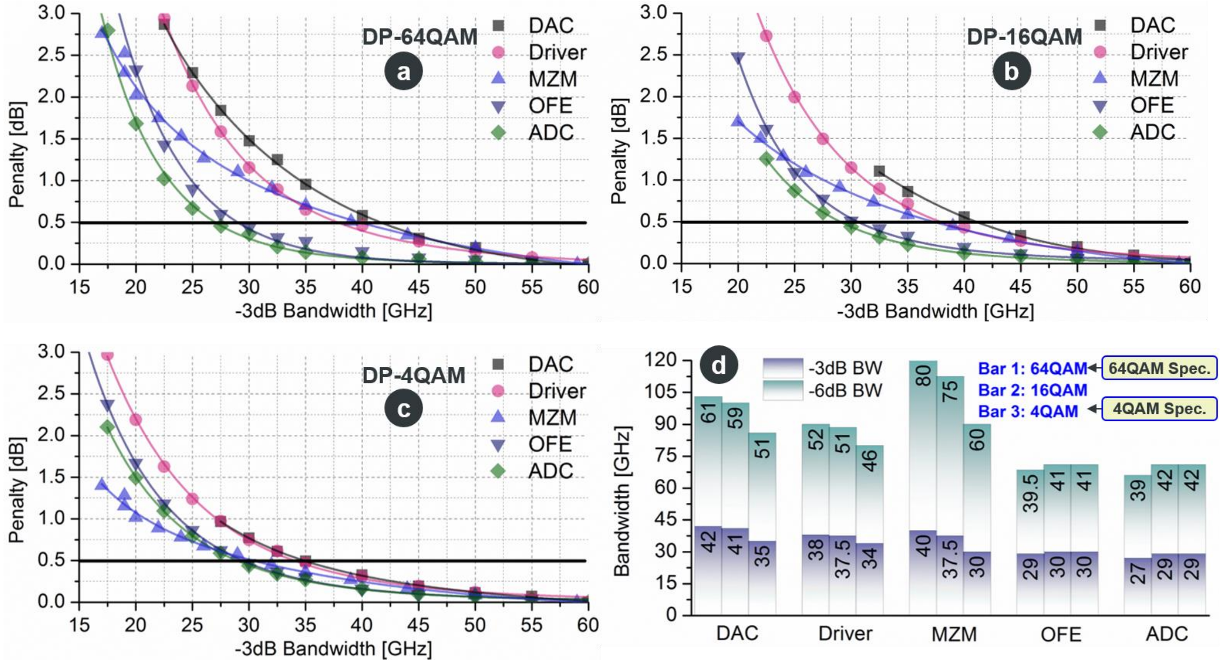
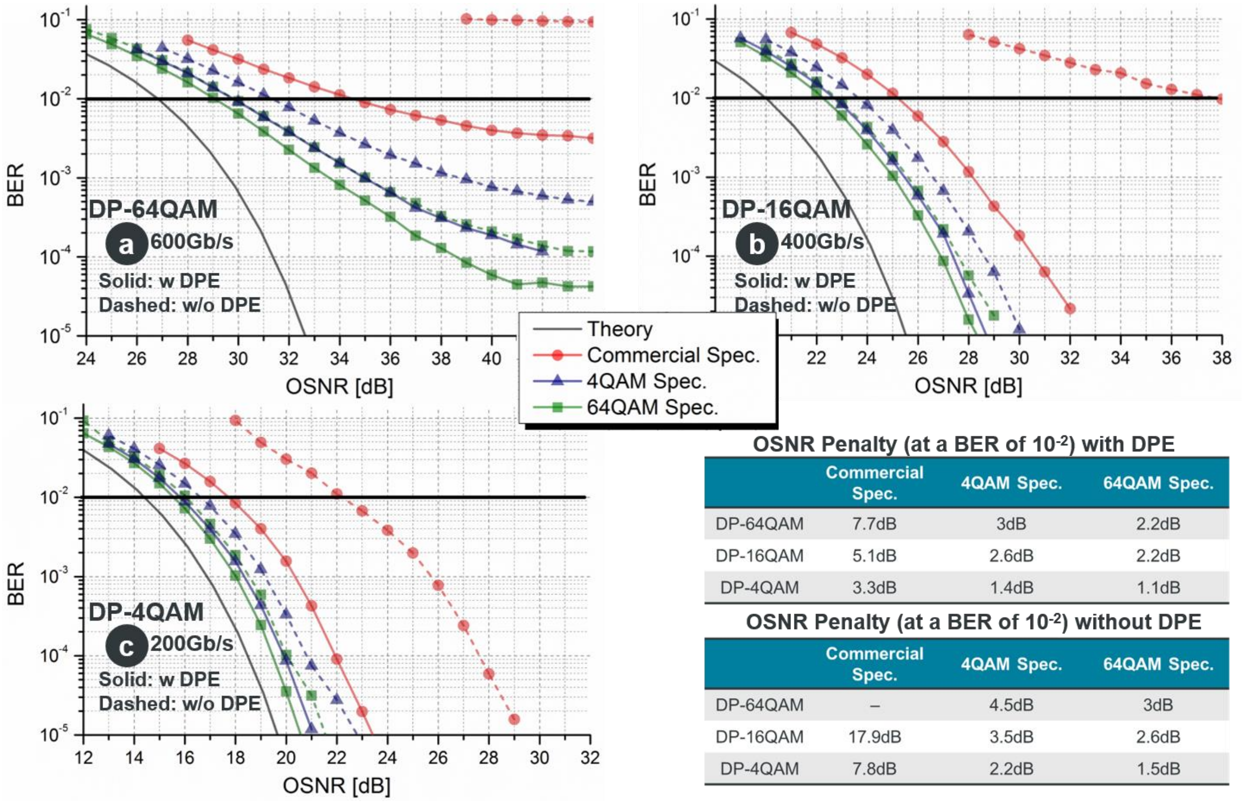


Fig. 2: Q penalty normalized to 60GHz bandwidth, assuming all other components with commercial specs. a) DP-64QAM, b) DP-16QAM, and c) DP-4QAM, d) -3dB and -6dB bandwidth for 0.5dB penalty points in a), b) and c).

Fig. 2d shows evolution of -3dB and -6dB bandwidth, at 0.5dB penalty point, for the three modulation formats as a function of different components. Again, larger variation is seen for transmitter bandwidths, both at -3dB and -6dB measurement points. Also, it can be seen that while DP-64QAM necessitates higher bandwidth for transmitter components, compared to lower order modulation, the trend is reversed for the receiver components, as DP-16QAM and DP-4QAM are more tolerant to commercial transmitter bandwidth constraints.



OSNR Penalty (at a BER of 10^{-2}) with DPE

	Commercial Spec.	4QAM Spec.	64QAM Spec.
DP-64QAM	7.7dB	3dB	2.2dB
DP-16QAM	5.1dB	2.6dB	2.2dB
DP-4QAM	3.3dB	1.4dB	1.1dB

OSNR Penalty (at a BER of 10^{-2}) without DPE

	Commercial Spec.	4QAM Spec.	64QAM Spec.
DP-64QAM	–	4.5dB	3dB
DP-16QAM	17.9dB	3.5dB	2.6dB
DP-4QAM	7.8dB	2.2dB	1.5dB

Fig. 3: BER vs. OSNR for Commercial Spec. (see Fig. 1a), 4QAM Spec., and 64QAM Spec. (see Fig. 2d). a) DP-64QAM, b) DP-16QAM, and c) DP-4QAM. Tables shows OSNR penalty, w.r.t theory. DPE: Digital pre-emphasis

Fig. 3 depicts waterfall curves for current commercial components (Fig. 1a), and next-generation components based on DP-4QAM and DP-64QAM bandwidth requirements at 0.5dB penalty (Fig. 2d), termed as *4QAM Spec.* and *64QAM Spec.*, respectively. As expected, OSNR penalties, w.r.t theory, reduce with decreasing modulation order, best performance is enabled by *64QAM Spec.*, and that DPE enables substantial improvements, especially for higher order modulation at lower bandwidth specifications. It is worth mentioning that we have only pre-emphasized the DAC, as the extent of DPE (considering other components) significantly trades off with transmit output power and DAC resolution; and effectively transceivers may not be fully pre-emphasized due to practical constraints.

The specific OSNR penalties at a BER of 10^{-2} are summarized in the tables. It can be seen that while *64QAM Spec.* enables penalties as low as 2.2dB for DP-64QAM and DP-16QAM, and 1.1dB for DP-4QAM, the component specifications may be relaxed, at the cost of 0.8dB worst-case penalty for DP-64QAM, by using *4QAM Spec.* with DPE (similar performance as *64QAM Spec.* without DPE).

4. Conclusions

We presented a systematic study on the entire transceiver chain bandwidth requirements for 64Gbaud coherent transceivers, employing DP-64QAM, DP-16QAM and DP-4QAM. We showed that 64Gbaud transmission is mostly limited by transmitter-side components, particularly by the DAC bandwidth. Furthermore, we showed that even with digital pre-emphasis, current commercial components incur high OSNR penalties up to 7.7dB for DP-64QAM. Modest next-generation bandwidth improvements may reduce such worst-case penalties to 3dB or 2.2dB, for 4QAM and 64QAM based next-generation bandwidth specifications, respectively.

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5. References

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