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XXXVII Cycle

Innovative technologies for optical access towards 100 Gbit/s and beyond

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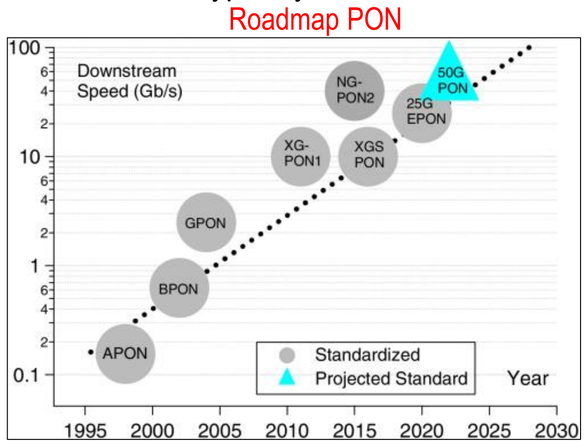
Research context and motivation

- The **PON** (Passive Optical Network) is a fiber-optic architecture that provides network access to end users with point-to-multipoint connections, typically for Fiber-to-the-Home (FTTH) applications.
- In September 2021, the ITU-T ratified the **50G-PON** standard and from 2024 it will be used as the standard for the PON architecture. The need to increase the flow of information along this architecture leads to find innovative technologies to achieve this goal and to characterize them.

Roadmap PON

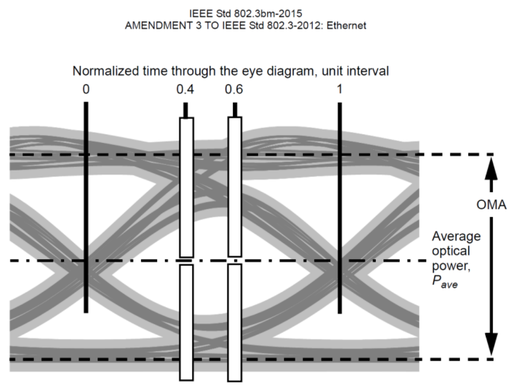


Graph taken from https://doi.org/10.1364/JOCN.403500

- For signal characterization, one technique used is the eye diagram opening. It shows the intensity of the received or transmitted optical power levels and, as a function of the distance between them, indicates the quality of the signal. However, this technique is most reliable at a transmission rate of 1 Gbit/s.
- For this reason, a different technique such as TDP (Transmitted Dispersion Penalty) was chosen as a solution, but due to its high cost and limitation to 10 Gb/s, it was soon replaced by TDEC.
- **TDEC** (Transmission Dispersion Eye Closure) is an economical technique that can evaluate the performance of a transmitter by means of the eye diagram experimental measurements. It has been adapted by the ITU for the 50 G-PON architecture.

Addressed research questions/problems

- TDEC is an IEEE standard developed by Keysight on their sampling oscilloscope. This standard is described into the **IEEE 803.2-2015** and into the **ITU-T G.9804.3 (09/2021).**
- To evaluate the TDEC, it is necessary to:
  1. Perform the eye diagram measurements
  2. Evaluate 4 histograms of the power levels distribution in two time's instants (0.425 UI and 0.575 UI)
  3. Add virtual noise at these distributions until a target BER is reached and select only the time's windows with the minor noise σ
  4. Evaluate the noise (σ_{ideal}) to be add to reach a target BER if the signal is ideal (signal without noise).
  5. Evaluate the TDEC as $\boldsymbol{TDEC = 10log_{10}(\frac{\sigma_{ideal}}{\sigma})}$

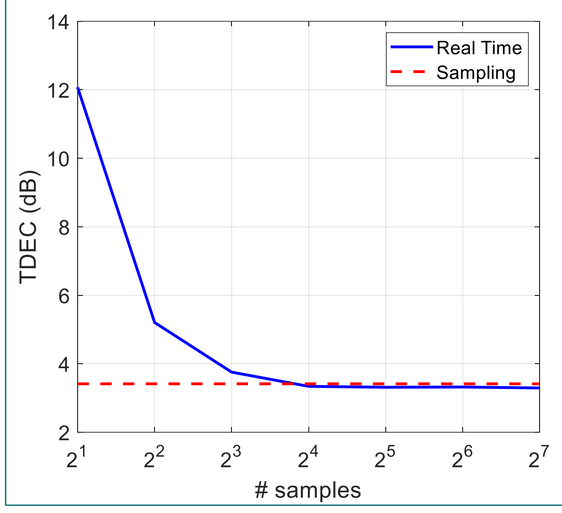


- The TDEC can be evaluated directly after the transmitter (in this case it is called TEC) or after the fiber, typically 20 km long. In both configurations, the method for calculating the TDEC is the same. Furthermore, the standard suggests using a known sequence of 32,762 bits for the TDEC correct evaluation.
- If the transmission speed is 25 Gbit/s the previous steps should be sufficient, however for 50G-PON it is mandatory to add a **Bessel** filter followed by an optimized 13-tap linear **equalization** in order to obtain the minimum mean square error.
- This standard is very detailed, but its implementation can be achieved with dedicated instruments (sampling oscilloscope). Furthermore, the dependency of certain parameters and how the TDEC value may change with different settings or equalizations is unknown.

Submitted and published works

Novel contributions

- The TDEC is studied with the **real-time oscilloscope** instead of the sampling oscilloscope, and the minimum number of samples per bit that produces a reasonable TDEC value is found:
  - The TDEC value obtained after 16 samples/bit is the same as that obtained with the sampling oscilloscope (graph on the left).
- The difference between two types of equalizations**, Zero Forcing (ZF)** and **Minimum Mean Square Error (MMSE)**, is studied in both simulation and experimental data:
  - Ceq (noise enhancement factor) and TDEC are lower in MMSE than in ZF.



$$Ceq = \int \frac{N_0}{2} \cdot |H_{Bes}(f)|^2 \cdot |H_{Eq}(f)|^2 \, df$$

$$TDEC = 10 \cdot log_{10}\left(Ceq \cdot \frac{\sigma_{ideal}}{\sigma}\right)$$

SIMULATION

BTW 0.3 Rs

	TDEC (dB)	Ceq (dB)
ZF	3.623	3.334
MMSE	3.323	2.648

BTW 0.5 Rs

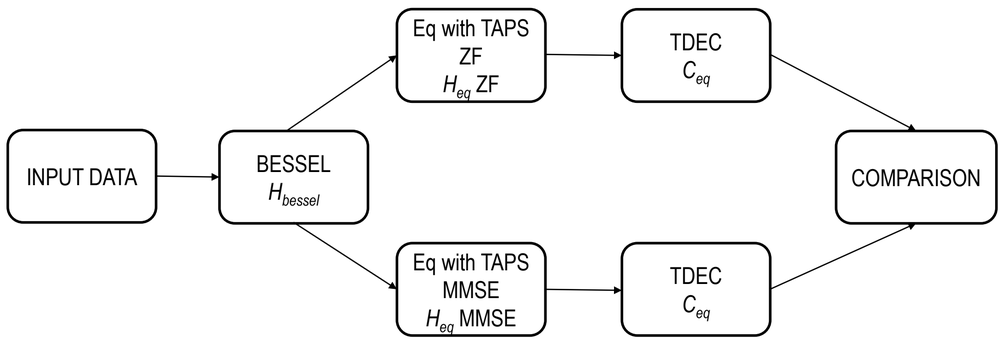
	TDEC (dB)	Ceq (dB)
ZF	1.810	1.505
MMSE	1.469	1.213

EXPERIMENTAL

	TDEC (dB)	Ceq (dB)
ZF	3.314	3.287
MMSE	3.262	2.425

Adopted methodologies

- The results shown refer to an acquisition without fiber and transmitting the recommended ITU sequence.
- The speed is 50 Gbit/s, the sampling frequency is 200 GHz and the Bessel filter bandwidth is 18.75 GHz.
- As an innovative contribution, a real-time oscilloscope was used, with 4 samples/bit resampled to **32 samples/bits**. Two different types of equalization can be used for the evaluation of TDEC:
  - For ZF, the standard is followed, but since the number of samples is different, a method is introduced in which **32 parallel equalizers** are implemented and the one that produced the lowest TDEC value is selected.
  - In MMSE, **noise is added** until a BER target is reached. Once the taps of this equalizer are found, the sequence is equalized without noise and the TDEC evaluation standard is followed.



Actual and future work

- Writing a JOCN paper with the collaboration of Huawei on these results.
- The formula for evaluating TDEC varies depending on the type of receiver used: APD or PIN.
  - At this moment, there is not a TDEC formula for the **SOA + PIN**
- TDEC is evaluated with a known transmission sequence
  - Evaluation of the TDEC in a real transmission system where the **transmission** system is **unknown** and long sequences of '1' and '0' are not present for a correct evaluation of the power average.
- **TDEC-Q**: TDEC technique applied to a PAM-4 modulation

List of attended classes

- 01QWJBG - Information and communication theory (22/02/2022, credits 8)
- 03JSGOQ - Digital Communications (04/07/2022, credits: 6)
- 01RGGRV - Telemedicine and Distributed Healthcare (22/03/2022, credits: 4)
- 01DNYRV - Semiconductor light sources for engineers (12/09/2022, credits: 4)
- 01QORRV - Writing Scientific Papers in English (05/05/2022, credits: 3)
- 24 CFU CFIS Formazione insegnati Piemonte

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering