

OFC2024 Sunday Workshop

An introduction to single-carrier vs. multi-carrier coherent PON

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Acknowledgments

- I like to thank the following people/groups for sharing with me their technical views on this talk topics:
 - The EU Horizon Europe project ALLEGRO
 - Exhibiting also at OFC2024 ALLEGRO at booth # 3621
 - The Telecom Italia (TIM) team on optical access
 - Annachiara Pagano, Maurizio Valvo, Roberto Mercinelli
 - The PhotoNext Team on optical access at POLITO
 - Giuseppe Rizzelli, Mariacristina Casasco, Valter Ferrero,
 - And my ex-collaborator Pablo Torres, now in Infinera
 - www.photonext.polito.it

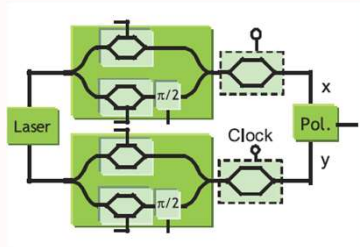




Single-carrier vs. multi-carrier coherent

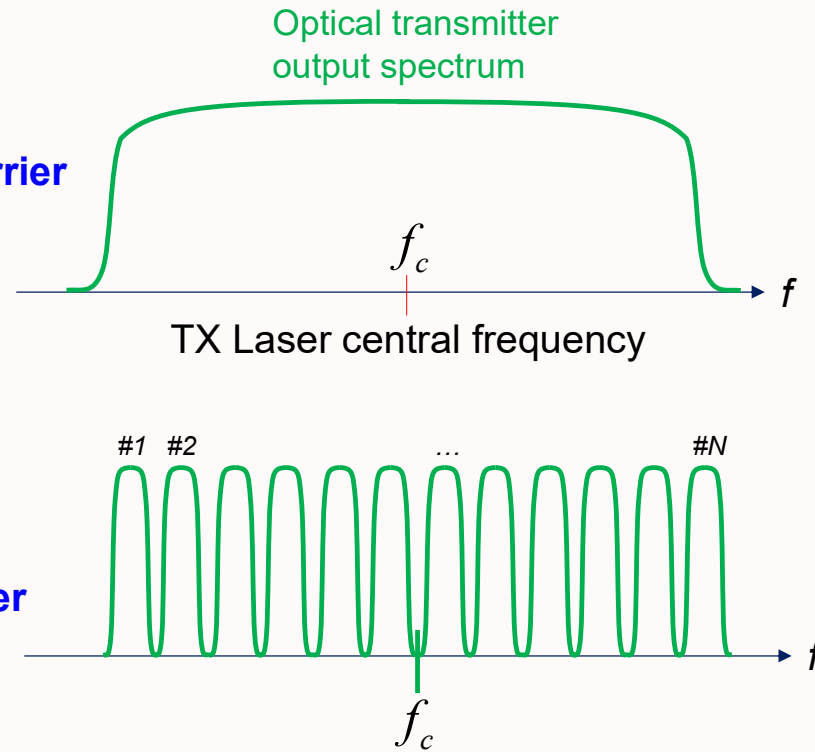


- ...just to touch base on the topic of the workshop ☺



Single-carrier

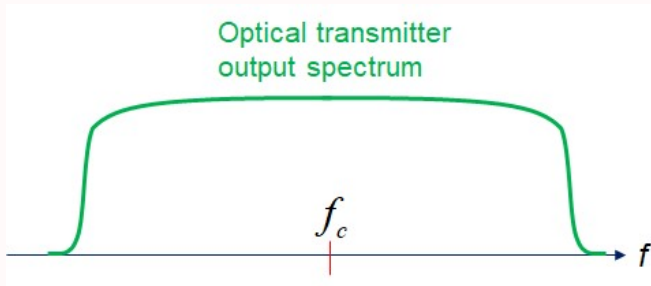
Multi-carrier



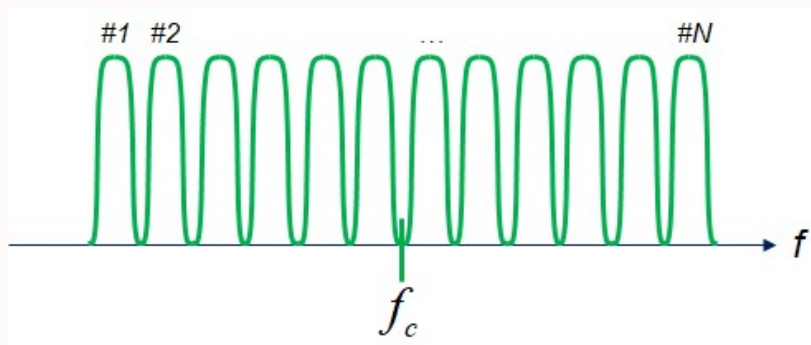
Most commonly adopted solution for long-haul coherent:
 On each transmitted wavelength:
a single PM-QAM modulation with Nyquist-shaped spectrum

Alternative solution:
 On each transmitted wavelength:
traffic is split on N "parallel" PM-QAM modulations over N electrically generated subcarriers

Focus of my (short) talk today

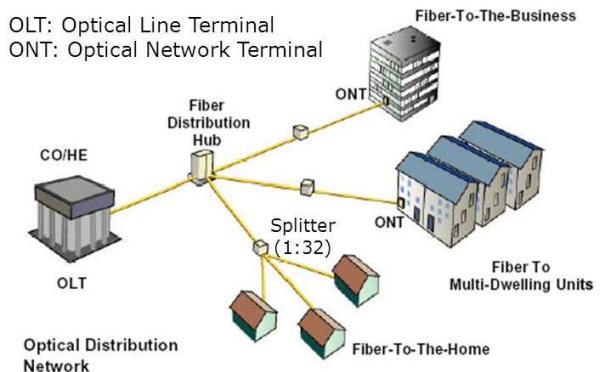


- Technical **pros** and **cons** of single-carrier vs. multi carrier in the specific scenario of future ultra-high bit rate coherent PON



Passive Optical Network (PON)

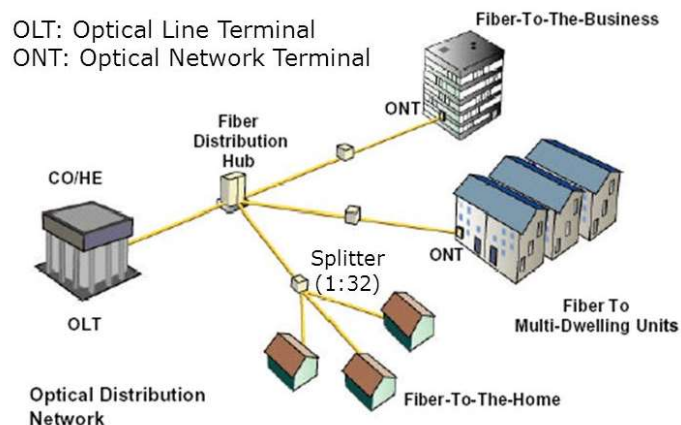
OLT: Optical Line Terminal
ONT: Optical Network Terminal



What's so "special" about PON at the physical layer?

- **Point-to-multipoint**
 - Typical target split-factor: up to 64 users (at least)
- **A multiplexing strategy for shared access**
 - Time Division Multiplexing (TDMA) so far in standards
- **Bidirectional transmission on a single fiber**
- **Very high Optical Distribution Network (ODN) loss**

Passive Optical Network (PON)



From latest ITU-T standard 50G-PON:

- Class N1: 29 dB → "minimum" target loss for practical PON: 29 dB
 - Class N2: 31 dB
 - Class E1: 33 dB
 - Class E2: 35 dB
- 20 km in O-band (0.4dB/km) → 8dB
 - 1x64 splitter → 18 dB
 - Extra loss → 2-3 dB

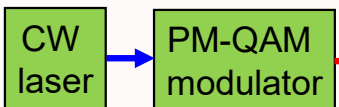


Why PON may jump from direct-detection to coherent?

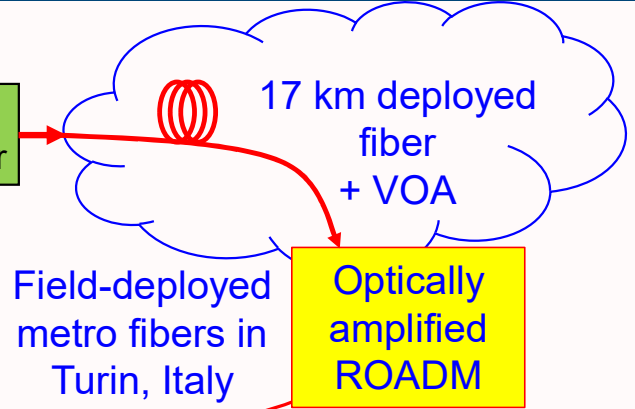
- Latest PON standard: 50G-PON (ITU-T G.9804) still PAM-2 and [direct detection](#)
- What's next?
 1. [100G-PON](#)
 2. [200G-PON](#)
 3. [Extended reach PON](#)
- Particularly for the last two options, [chromatic dispersion tolerance and optical link power budget would be super-tight for direct-detection](#)
 - This is the [main rationale](#) for going towards Coherent PON

Our experiments on extended reach coherent PON scalability at 200-400 Gbit/s

PHOTONEXT



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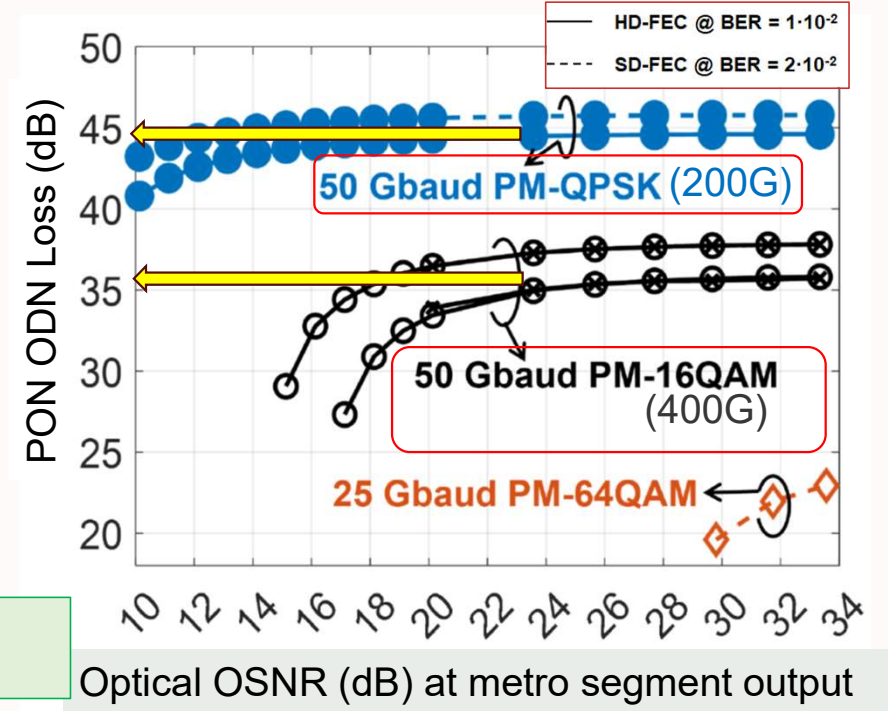


$$P_{fiber}^{TX} = +11 dBm$$

- Preliminary good news but...
- Reflections / MPI
 - Upstream burst mode
 - Wavelength plan
 - Network level issues

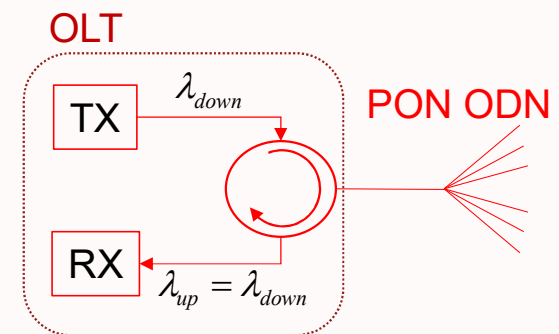
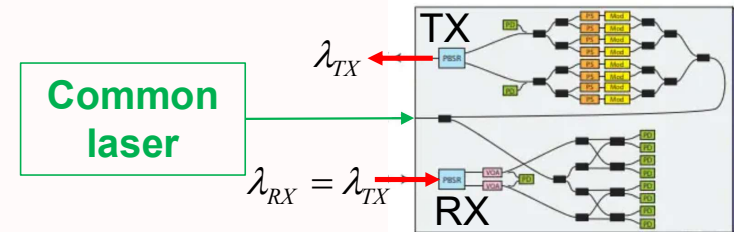
... besides techno-economics, that I will leave to the speakers after me 😊

Our paper at this conference
 Title: *Experimental Demonstration of In-Field 400G Coherent Metro-Access Convergence*
 Presenting Author: Giuseppe Rizzelli Martella
 Presentation ID: W1J.1 **Top-Scored OFC2024 paper**



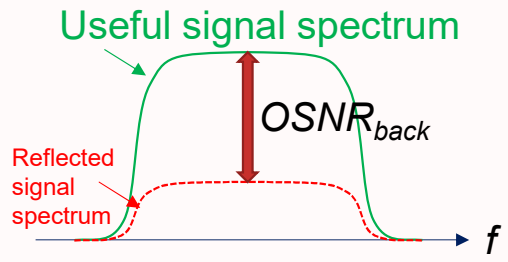
Bidirectional transmission over PON

- Commercial coherent transceivers so far use the same wavelength in both directions
 - A single laser inside the transceiver is used both for TX and LO RX
 - Lower CAPEX cost
 - Easier laser locking
- Can we use this setup "as is" over a PON?
 - A circulator needed at both ONU and OLT sides
 - BUT what about the impact of back-reflections?

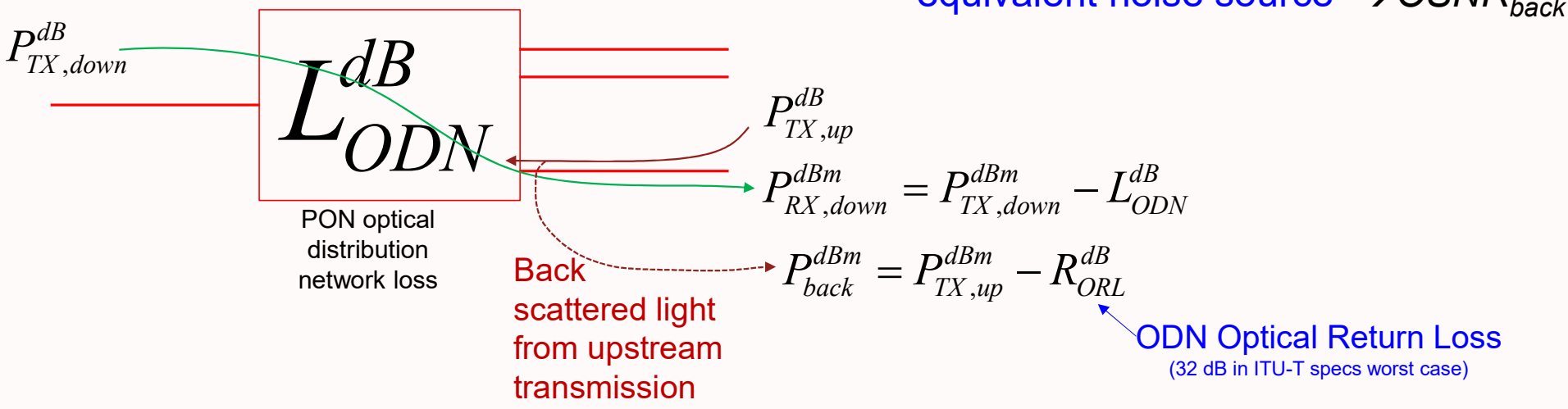




Same wavelength, single carrier coherent over bidirectional PON?



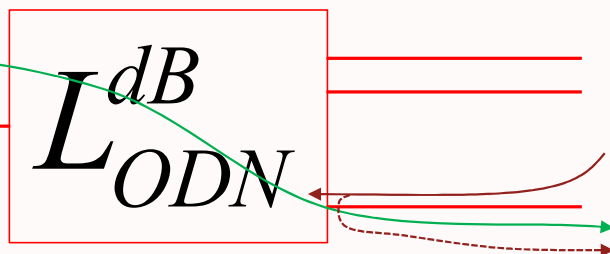
- A super-simplified analysis of the impact of back reflections
 - Let's assume same wavelength, single carrier coherent transceivers
 - In-band coherent crosstalk = equivalent noise source $\rightarrow OSNR_{back}$





Same wavelength single carrier coherent

PON optical distribution network loss



- $OSNR_{back}$ due to back-reflections alone:

$$OSNR_{back}^{dB} = P_{RX,down}^{dBm} - P_{back}^{dBm}$$

$$= P_{TX,down}^{dBm} - L_{ODN}^{dB} - P_{TX,up}^{dBm} + R_{ORL}^{dB}$$

- Let's assume for simplicity that the transmitted power is the same in both directions

$$OSNR_{back}^{dB} = R_{ORL}^{dB} - L_{ODN}^{dB}$$

- Typical ITU-T ODN values

$$R_{ORL}^{dB} = 32dB \quad R_{ODN}^{dB} = 31dB$$

$$OSNR_{back}^{dB} = R_{ORL}^{dB} - L_{ODN}^{dB} = 1dB !!!$$

- Take away message #1:

Same wavelength, single carrier on "true" ITU-T PON ODN is impossible



So what?

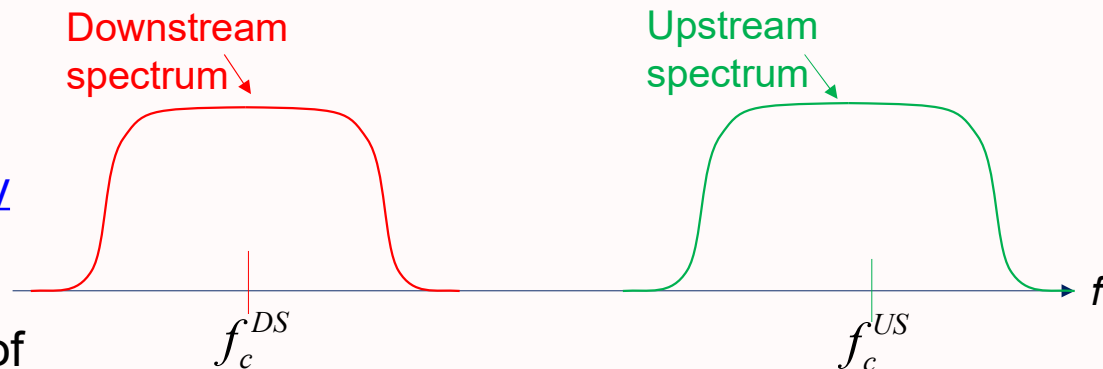
Two possible options... that are the targets of today workshop

1. Single-carrier coherent on two spectrally separated wavelengths for DS and US

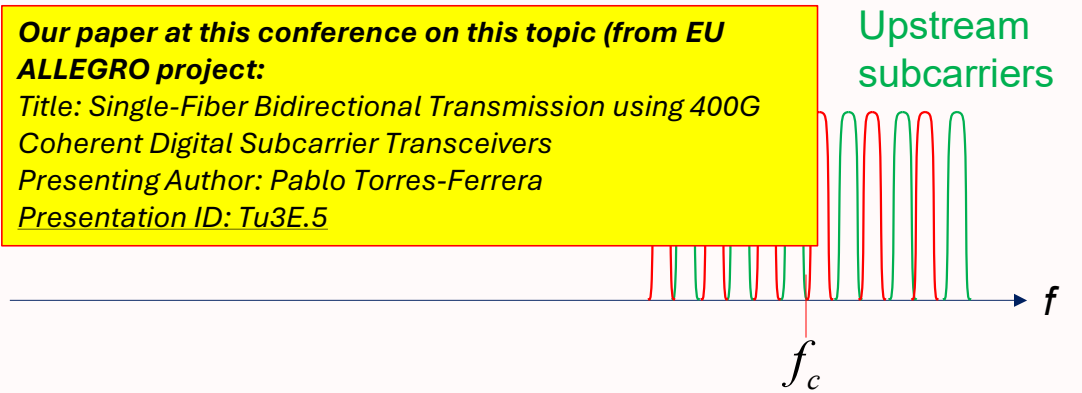
- as in "traditional" IM-DD PON
- Would require a significant re-design of current coherent transceivers
 - Two separated lasers
 - Slightly modified DSP for laser locking

2. Multi-carrier coherent on same central wavelength for DS and US

- But using spectrally separated subcarriers for the two directions

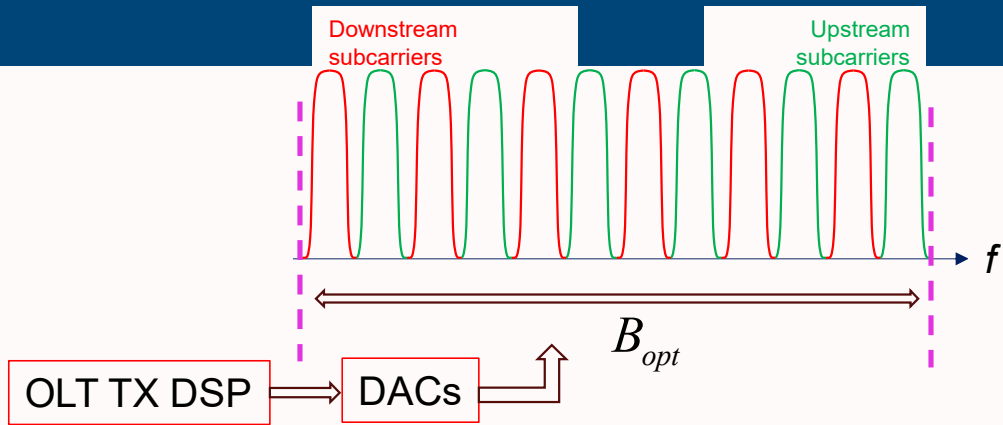


Our paper at this conference on this topic (from EU ALLEGRO project):
Title: Single-Fiber Bidirectional Transmission using 400G Coherent Digital Subcarrier Transceivers
Presenting Author: Pablo Torres-Ferrera
Presentation ID: Tu3E.5



The trade-off between the two solutions at the physical layer

- Multi-carrier
 - PRO: Same laser for both directions
 - Simpler optoelectronic
 - easier “wavelength locking” in ONUs
 - CON: For a given ADC and DAC sample rate, the achievable baud rate per direction is divided by two
 - At least at the OLT
- Single-carrier
 - Just the opposite...



Take away message #2 and key question for the following speakers: Techno-economically, which is “best” among these two options?

- 1) multi-carrier single laser, transceiver using US/DS interleaved subcarriers BUT accept the baud rate reduction by a factor of 2? (per direction)
- 2) single-carrier two lasers, transceivers achieving “full baud rate” given the ADC and DAC sampling rate



Network layer: multiplexing strategy for N_{ONU}

Another key question for the following speakers: multiplexing strategy?

- Single-carrier
 - TDMA is a must

- Multi-carrier
 - a dedicated subcarrier per ONU → TDMA is not needed
 - BUT statistical multiplexing advantages of TDMA would be lost

 - IF $N_{ONU} > N_{SC}$, then TDMA is anyway needed on top of subcarrier multiplexing



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The slides of my ECOC2024 Tutorial on PON future evolution are available at this QR-code link

Interested in our papers on PON?
Follow this QR-code!



Email: roberto.gaudino@polito.it



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BACKUP SLIDES



Why PON may jump from direct-detection to coherent?

- ALL ITU-T and PON standards up to the recently released 50G-PON (ITU-T G.9804) are based on [direct detection](#)
 - And moreover, they ALL are based only on PAM-2
 - PAM-4 has been discussed but not yet implemented
- What's next?
 - [100G-PON](#): it may likely still be direct detection
 - But truly at the limit in terms of optical link budget AND chromatic dispersion tolerance
 - The ODN can remain passive, but optical amplification surely needed at one or both ends of the link
 - [200G-PON](#): **here is where direct detection would be technically super-hard → coherent PON?**
 - The chromatic dispersion tolerance at 20km would become super-critical even with PAM-4
 - And optical link budget may be critical even when using optical amplification at both ends of the link
 - [Extended reach PON](#): there is a growing interest (for instance several EU Horizon projects) on an all-optical convergence between metro and PON
 - Again, coherent technologies may greatly help for this target