Extending EPON link budgets *without* new PMD definitions

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Extending PONs without *any* new PMD definition

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- This presentation shows how EPON link budgets *are* being extended with present PMD definitions remaining intact. Two general categories of extension are:
  1. Extending the EPON link budgets, *keeping the network passive*
  2. Extending the EPON link budgets, and *adding active elements between OLT and ONU*

- All of these extensions use the *existing PMD definitions*, in ways that clearly were *neither intended or expected by the original framers* of the EPON PMD definitions.
  - All of these extensions have been created in *response to articulated carrier needs*.
- *Ongoing* EPON *technology developments* are changing how EPON PMD definitions are used.
  - » Modern OLT MACs can support hundreds and hundreds of simultaneous ONUs.
  - » Modern PIC-based OLT transceivers incorporate CO-splitting, OTDRs and loss-less optical combiners (MCRs)
- This opens some interesting *philosophical questions* as the study group explores potential new EPON PMD definitions.

Extended ***passive*** optical networks

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- A generic extension of EPON link budget can be applied to *either* reach or split.
- Using, established, well-known technology, EPON OLT ports (from a single OLT MAC-domain) can be split (or duplicated) almost indefinitely – within the confines of the central office.
- Recent advances in photonic integrated circuits (PIC) technology have made these techniques viable for *any* PON.
- These approaches increase the link-budget, while keeping the network passive.
- *ExEPON_1109_piehler_1.pdf* outlines the significant economic value of increasing the split-ratio (or number of optical ports) per OLT MAC-domain within the central office.

Extended passive optical networks – increasing the PON downstream split-ratio in the CO

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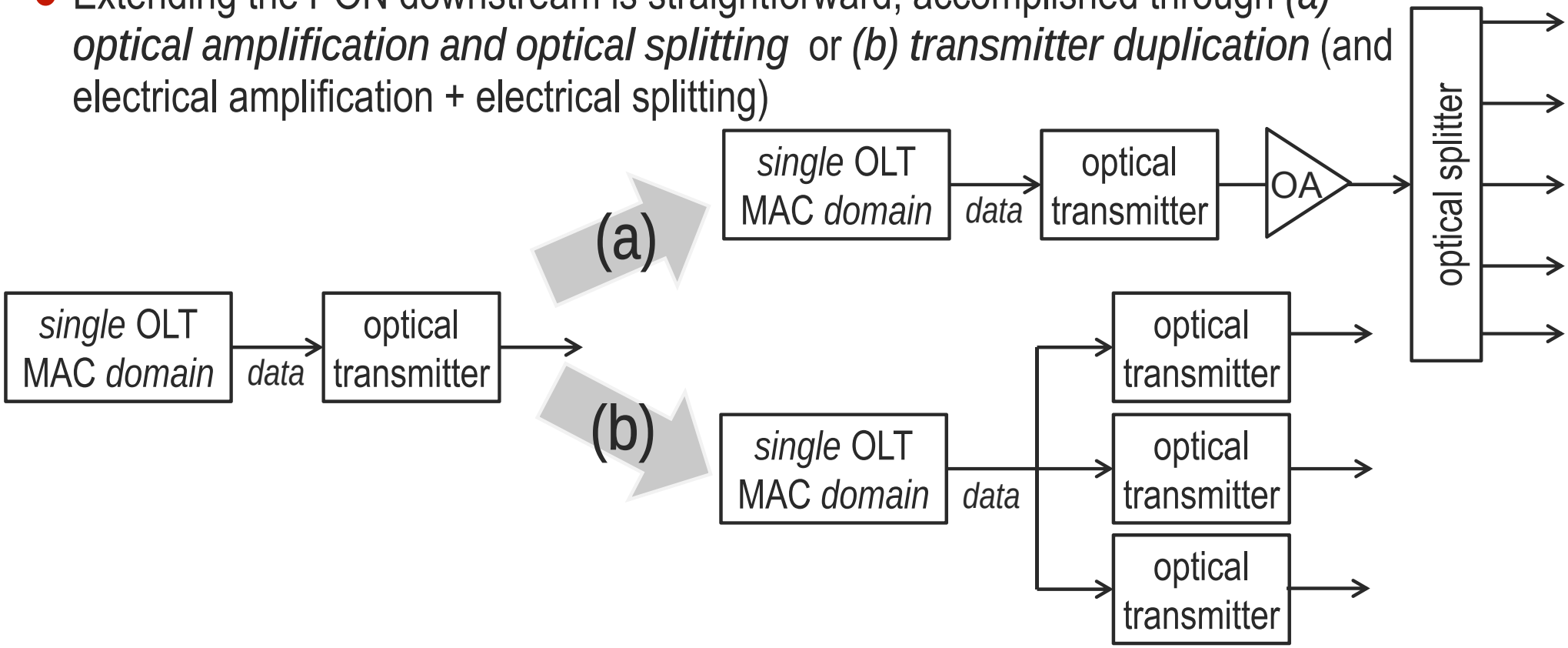
- Extending the PON downstream is straightforward, accomplished through *(a) optical amplification and optical splitting* or *(b) transmitter duplication* (and electrical amplification + electrical splitting)



- Due to the relatively high electrical or optical signal level at the OLT, the downstream signal can be split almost indefinitely without significant impact on the total link budget.
  - Example, a single RF video transmitter at a central office can serve 10,000 customers, using multiple levels of cascaded EDFAs and optical splitters.

Extended passive optical networks – the *loss-less* upstream signal combiner

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- It is well known that the upstream loss of a PON optical splitter can be eliminated by
  - An optical ***mode coupling receiver*** (b), coupling all fiber modes to a large photo-detector
  - Combining upstream signals in the analog (c) or digital (d) electrical domain[1,2].

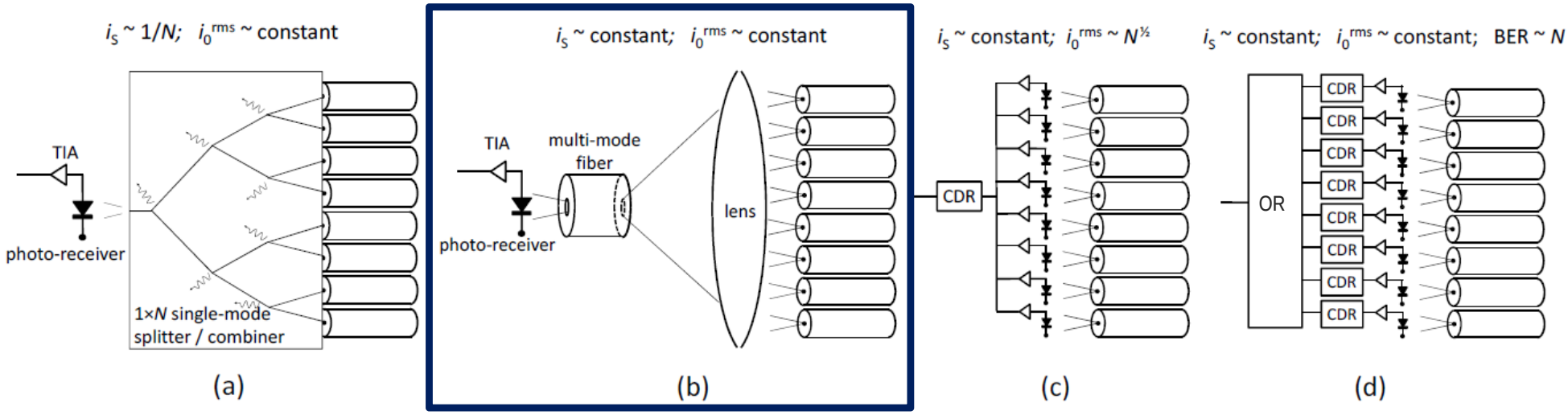


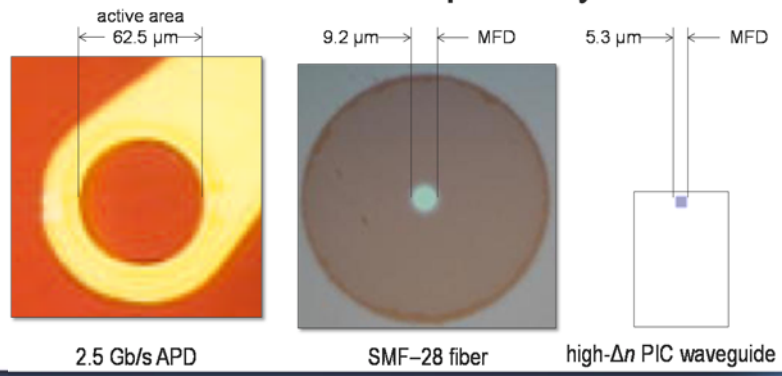
Fig. 1. Methods (b, c, d) for recovering upstream *waste-light* from N single-mode fibers compared with a $1\times N$ single-mode splitter (a). The signal and noise scalability with N is listed above each figure.

From [3]

i_s = photocurrent; i_0^{rms} = noise current in absence of signal

- A ***mode coupling receiver*** is *loss-less* and incurs no noise penalty for a TDMA upstream

An APD presents a large target, accommodating high-efficiency coupling from many upstream waveguide modes.



Extended ***passive*** optical networks – a 10G-EPON OLT with ***sixteen*** PR30 OLT ports

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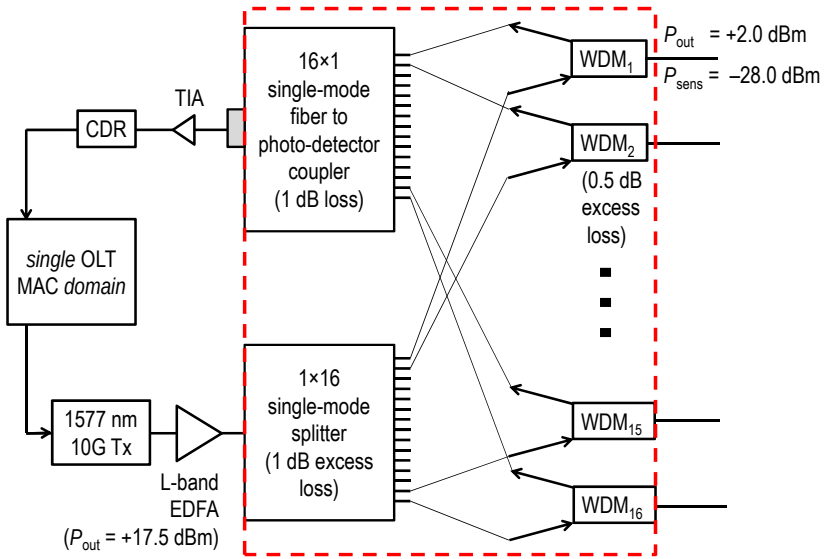
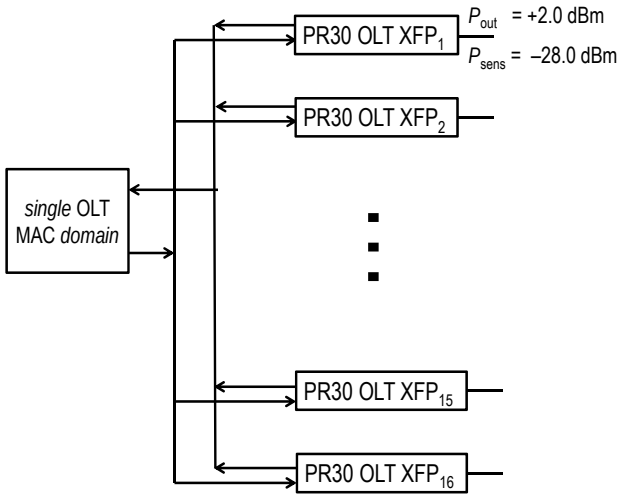
Note: even though there are multiple optical OLT ports per OLT MAC-domain, existing PMD definitions are still valid for each OLT port



Optical combine / split



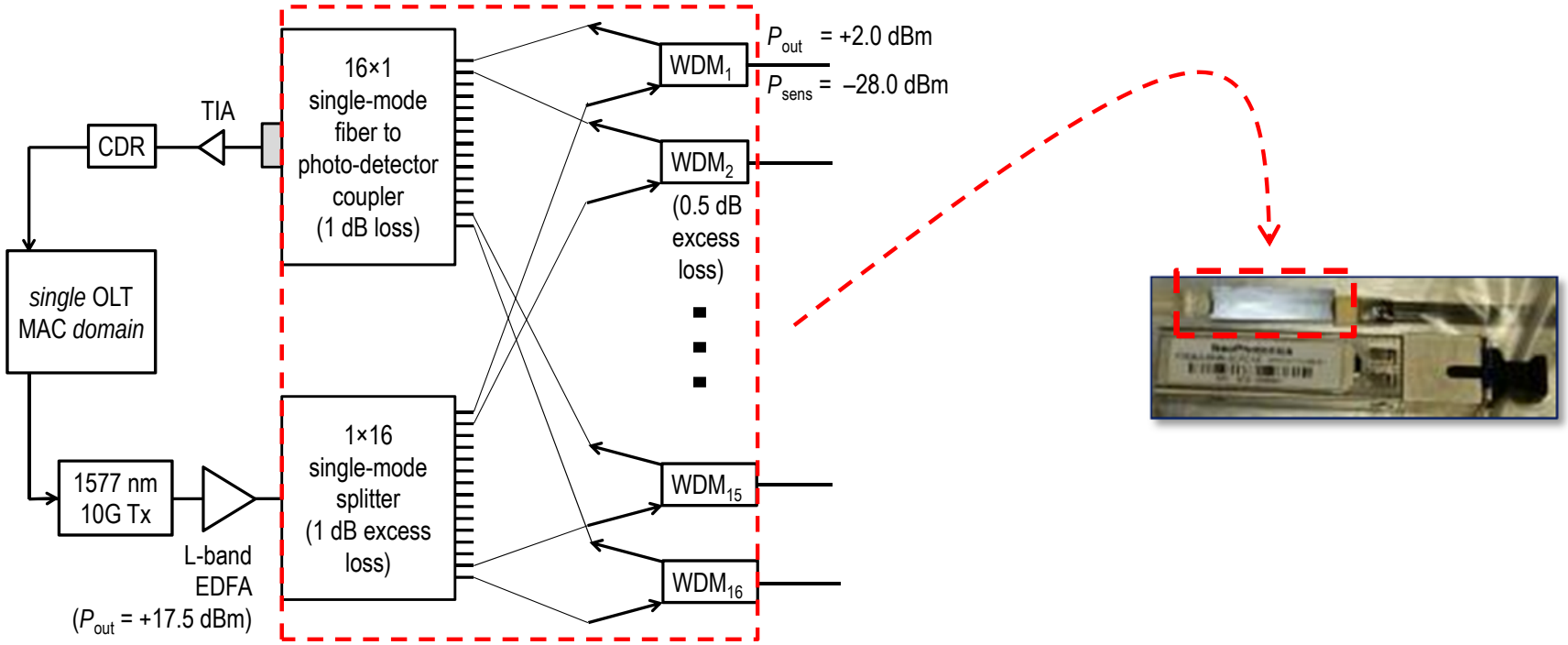
Electrical combine / split

- Requires *one* PR30 OLT Tx + *one* PR30 OLT Rx
- Requires *one* +17.5 dBm L-band EDFA
  - Single-λ (1577 nm), no gain flattening
- Requires *one* 1×16 optical splitter
- Requires ***one*** 16 (single-mode fiber) to single (multi-mode waveguide) coupler For examples see: [5–8]

- Requires *sixteen* PR30 OLT transceivers

Q: Why has this optical technique had little impact until today? A: The optimal technical solution for each of the constituents is different (planar, thin-film, fused fiber), making solutions bulky, and scale poorly with increasing split-ratio.

The optical splitter / MCR can be incorporated into a single photonic integrated circuit (PIC)



At NeoPhotonics we have incorporated all functionality of the 1×16 splitter combiner in the red box onto a single PLC less than 25 mm in length. (SFP module shown for scale.)

The strengths of the integrated optical solution are:

1. For low split ratios, (*e.g.* 1×2, 1×4) the solution can be integrated into a pluggable transceiver module, with optical amplification replaced by higher-power lasers, creating compact, 2- or 4-port OLT transceivers.
2. As split ratios increase, the optical integration insures that the overall cost of the solution scales sub-linearly with optical amplifier power. The electrical solution (cost of OLT transceivers) scales linearly with the split-ratio.

A philosophical question: What is a new PMD?

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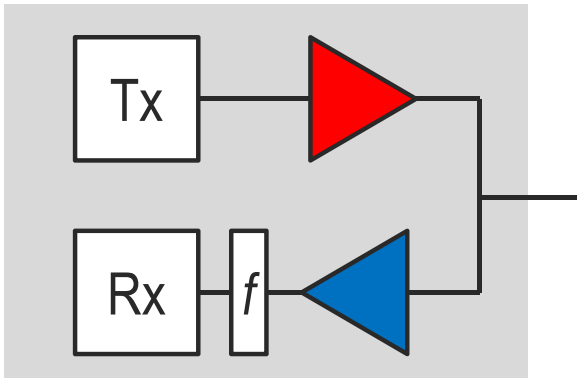
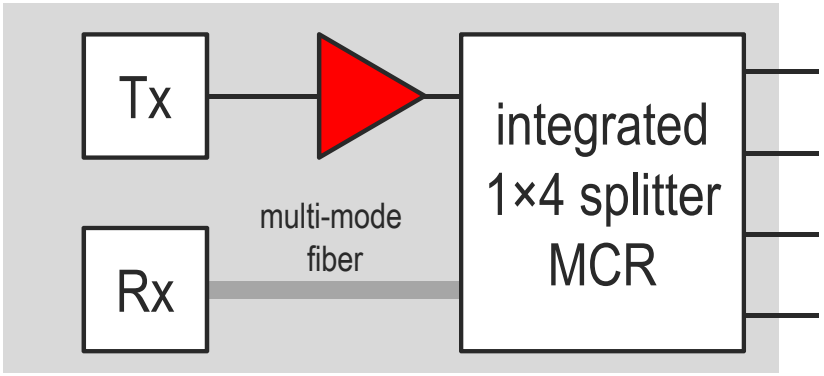
PMD_{new}:
A single-port
"PR50" OLT
transceiver



PMD_{old}:
A four-port
PR30 OLT
transceiver



PMD_{old}:
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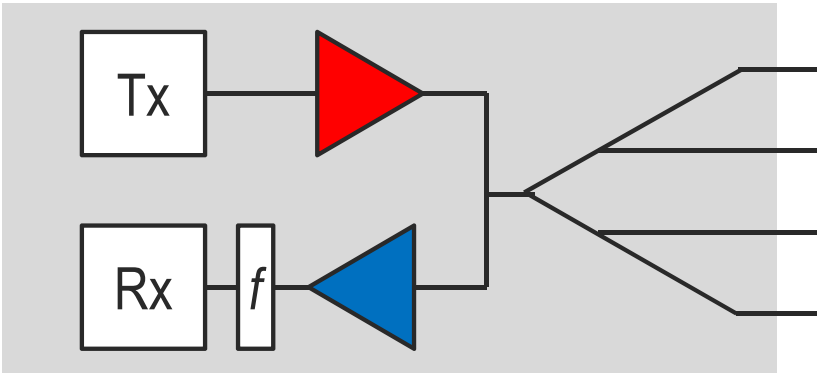

identical technology

identical performance

Is this a new or old PMD?

Extending PONs with active elements

- The active PON link extender also re-uses existing PMD definitions.
- Optical-to-electrical-to-optical (OEO) as well as mixed all-optical / OEO approaches are reviewed

OEO PON link extenders – two basic approaches

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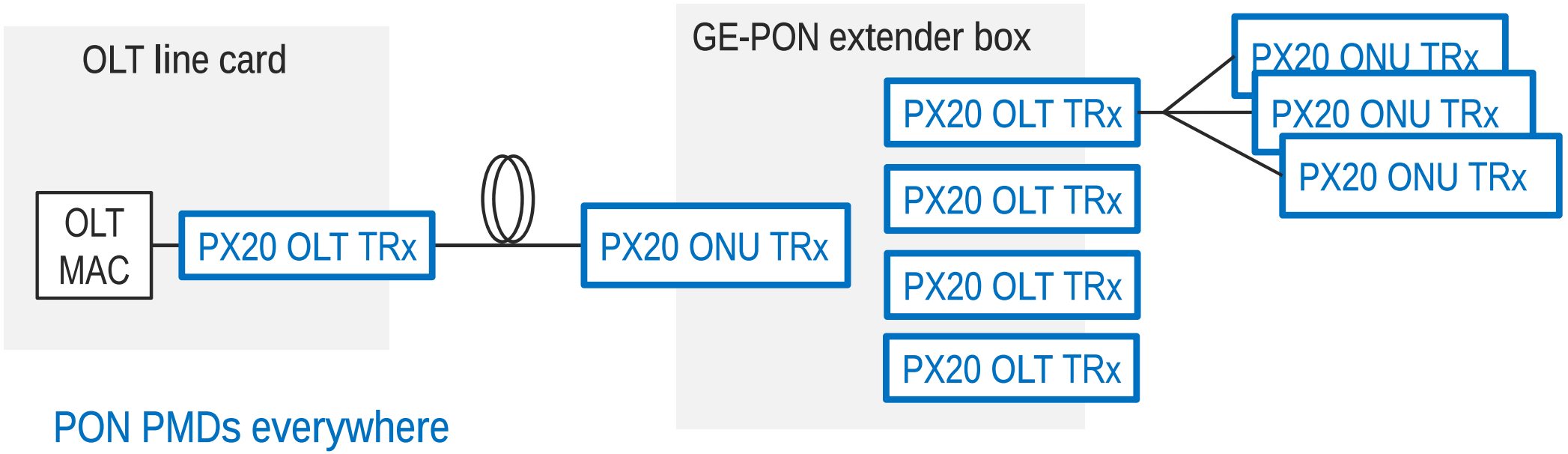
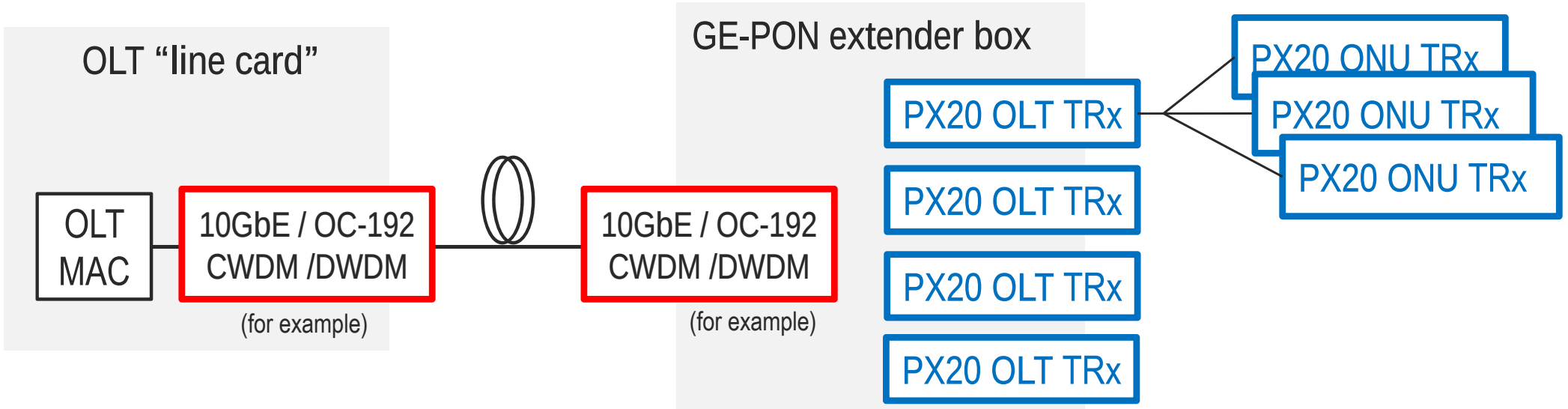
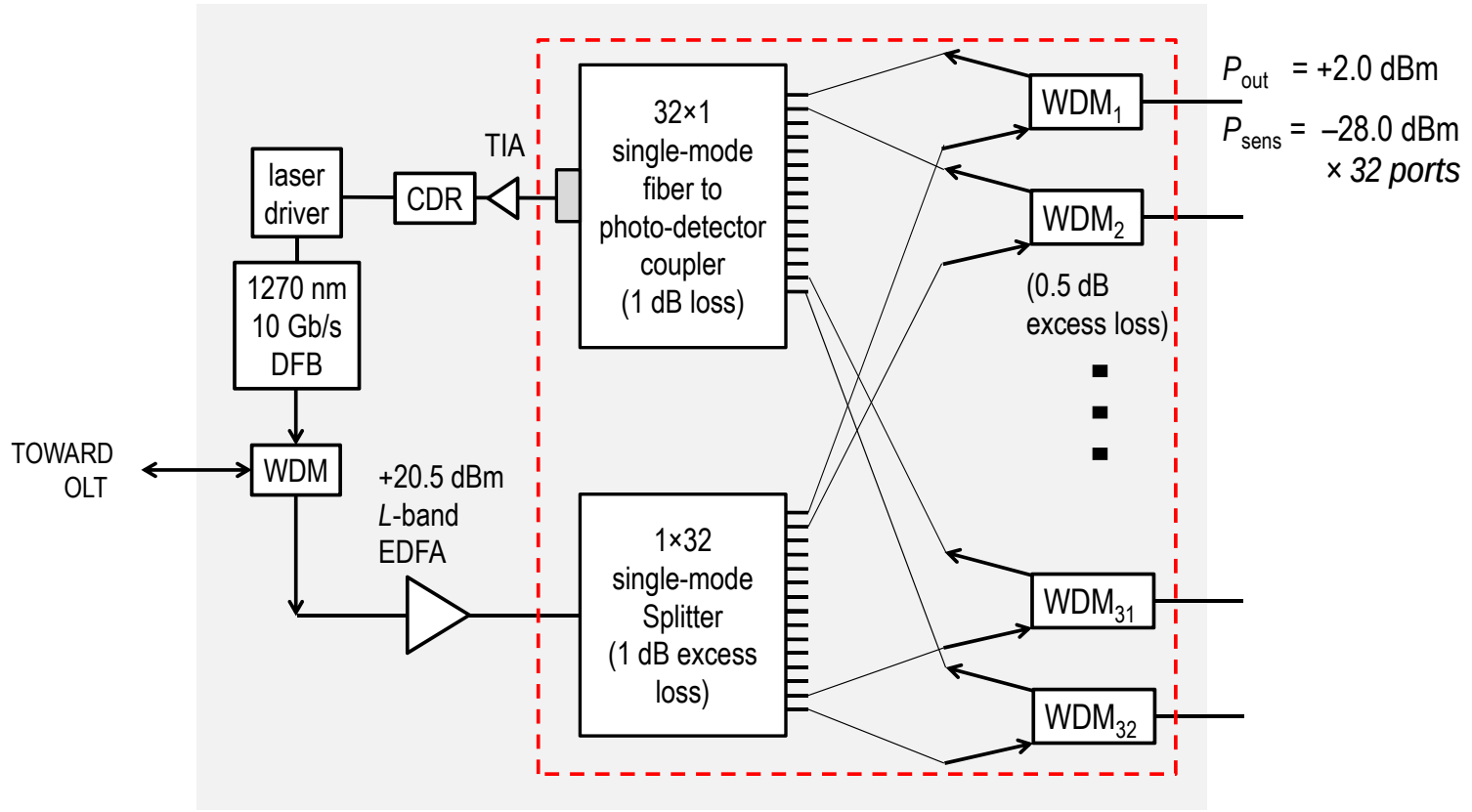


PON PMDs everywhere

PON PMDs only on distribution side of extender



A hybrid OEO / OOO link extender – with *thirty-two* PR30 ports



- Hybrid OEO / all-optical approaches are also possible.
- As in the case of the OLT, the ability to put all element in the red box onto a single PIC insures superior scalability with split-ratio.

Ongoing activity in the PON world impacts the way existing PMD definitions are used

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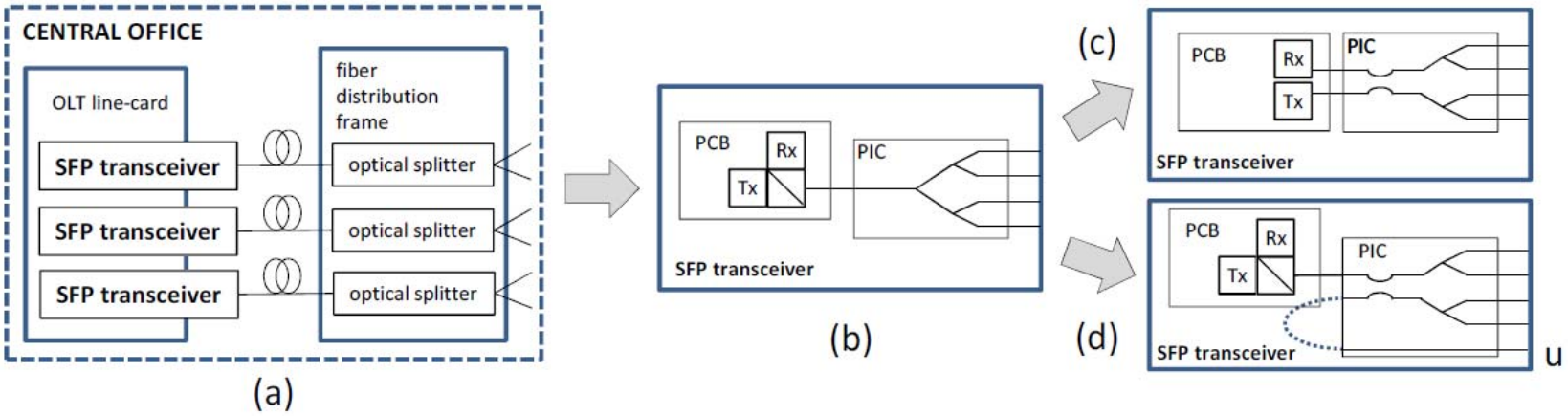
- *A modern OLT MAC* chip *controls hundreds and hundreds of ONUs* simultaneously.
  - Accommodating many more ONUs than allowed by the original PMD definition of link-budget
- *Modern OLT optical transceiver modules are becoming more sophisticated*
  - *Embedded OTDR*
  - *Central office passives move into the OLT optical transceiver module*



From [5]

Fig. 3. Alternate pathways to photonic integration.

- Benefits for the carrier of integration CO passives into OLT optical transceiver.
  - PON link budget improves by ~ 1 dB due to fewer connectors
  - Reduces central office floor-space (*OpEx savings*)
  - Reduces splitter costs (*CapEx savings*)

Summary

- *EPON link budgets are being extended to very high split-ratios today while using existing PMD definitions.*
- In some cases *distances are also extended without any altered PMD definitions*.
- *PMD definitions themselves have been extended* by technical advances and carrier demands.
- We should keep this in mind as we explore new EPON PMD definitions.