Unified Evolution-Ready 25/50/100 Gbps-EPON Architecture Proposal

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 Public

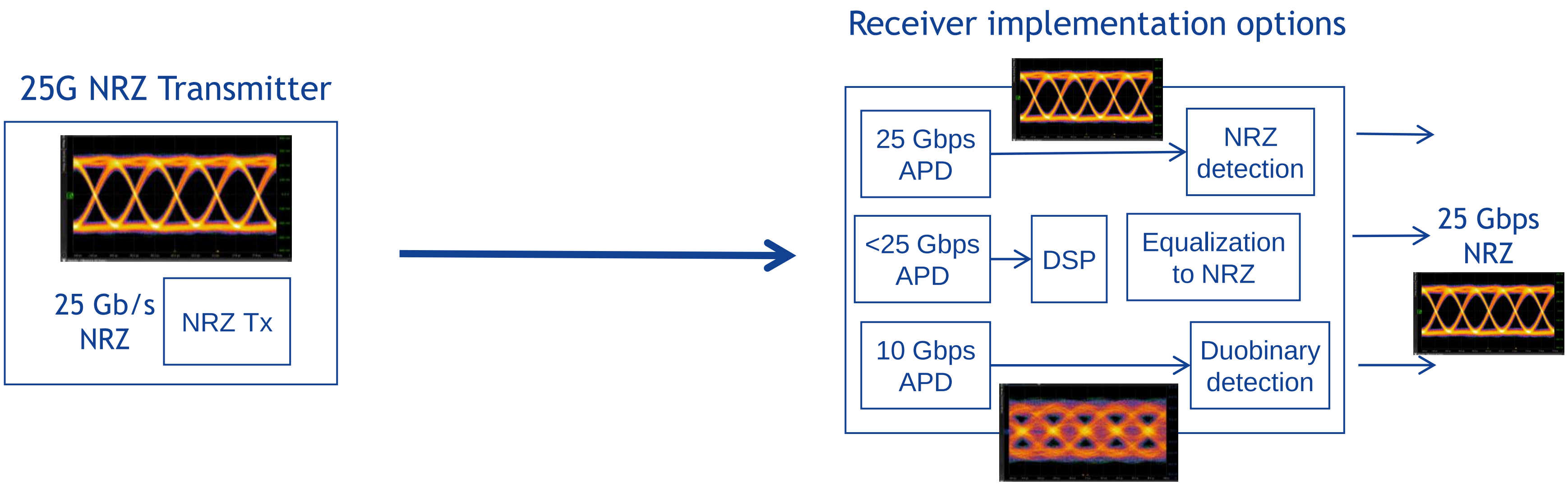
Cost-optimizing 25/50/100G EPON

- **At the Transmitter :**

- We should use 25G NRZ transmission leveraging high volume 25G data center components, in particular 25G DMLs and EMLs.

- **At the Receiver :**
  - Data center applications will not drive volumes of 25G APDs, so (initially) we need to rely on 10G APDs for low cost.
  - Electrical Duobinary (EDB) is a good low cost option to get 25G performance using 10G APD based receivers.
  - Another option would be to use a 10G APDs+DSP (MLSE/DFE) to equalize the signal back to NRZ.
  - Also 25G APDs might become low cost enough when technology matures and achieves high volumes, so we should not exclude regular NRZ detection for 25/50/100G EPON using 25G APDs.

We therefore propose an unified signaling architecture to support all receiver implementations



Unified signaling allows multiple receiver implementations on the same PON and enables risk mitigation by taking future cost evolutions into account as well

Of proposed implementations electrical duobinary will probably be the lowest cost initially. It is well understood and used by different groups in different applications

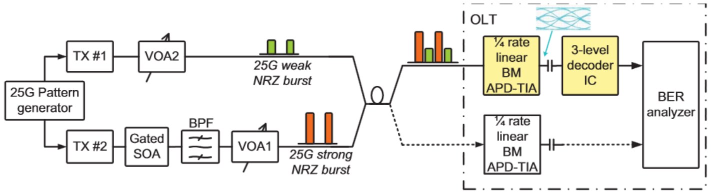


Fig. 2. Experimental setup used to characterize the BM-RX

25 Gbps PON, X. Yin et al. IMEC, OFC 2015

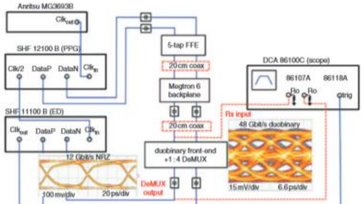


Fig. 1 *Experimental test setup for 48 Gbit/s duobinary serial transmission over 11.5-inch Megtron 6 backplane*

48 Gbps , Y. Ban et al. IMEC, Electronic Letters 2015

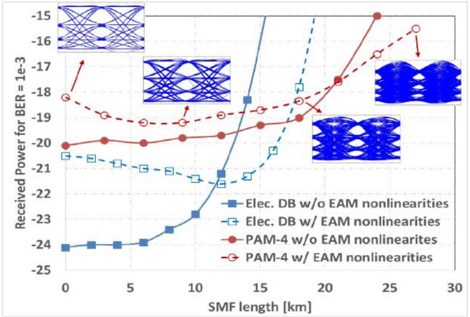


Fig. 5. Optical sensitivity at a BER of 10^{-3} versus fiber length for electrical Duobinary and PAM-4 subject to cases with and without EAM nonlinearities. The inset noise-free eye diagrams are for PAM-4 signal with EAM nonlinearities.

40 Gbps PON, J. Wei et al. ADVA ,Optics Express 2015

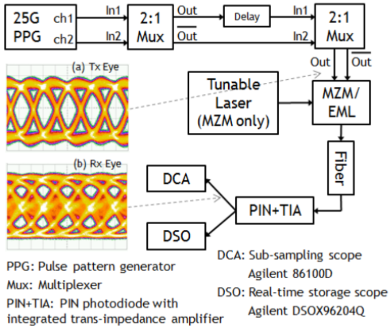


Fig. 1. Measurement setup for 103.125-Gb/s serial transmission. Eye diagram: (a) Electrical MZM drive signal. (b) Electrical received signal.

103 Gbps , J. Lee et al. Nokia , OFC 2014

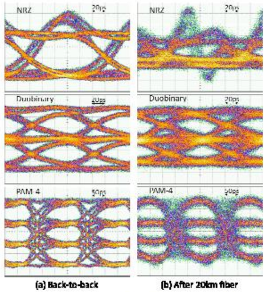


Fig. 4 Eye diagrams of 10Gb/s NRZ, duobinary and PAM-4 signals for (a) back-to-back and (b) after 20km transmission.

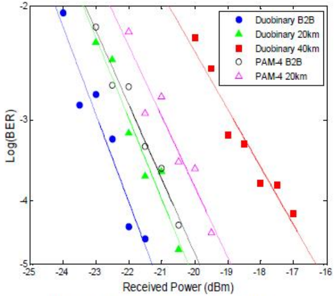


Fig. 5 Bit error rate for duobinary and PAM-4 signals.

10 Gbps PON, N. Cheng et al., Huawei, Asia Com. And Photonics, 2013

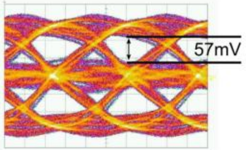


Figure 17: 56 Gb/s output eye-diagram of the transmitter.

56 Gbps , T. De Keulenaer et al. IMEC, DesignCon 2015

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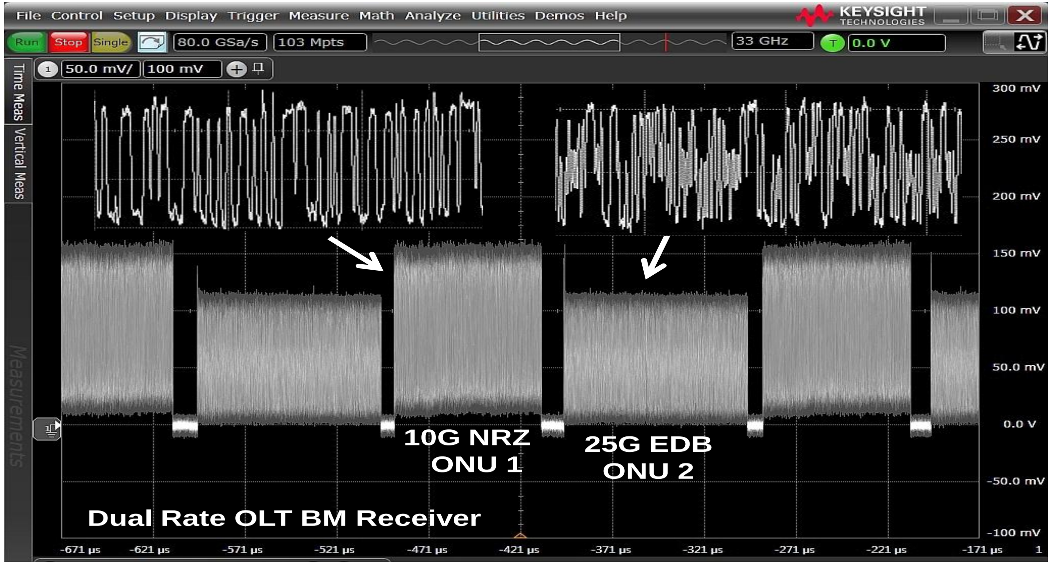
EDB also simplifies dual rate BM receiver at OLT if TDM co-existence with 10G EPON is needed



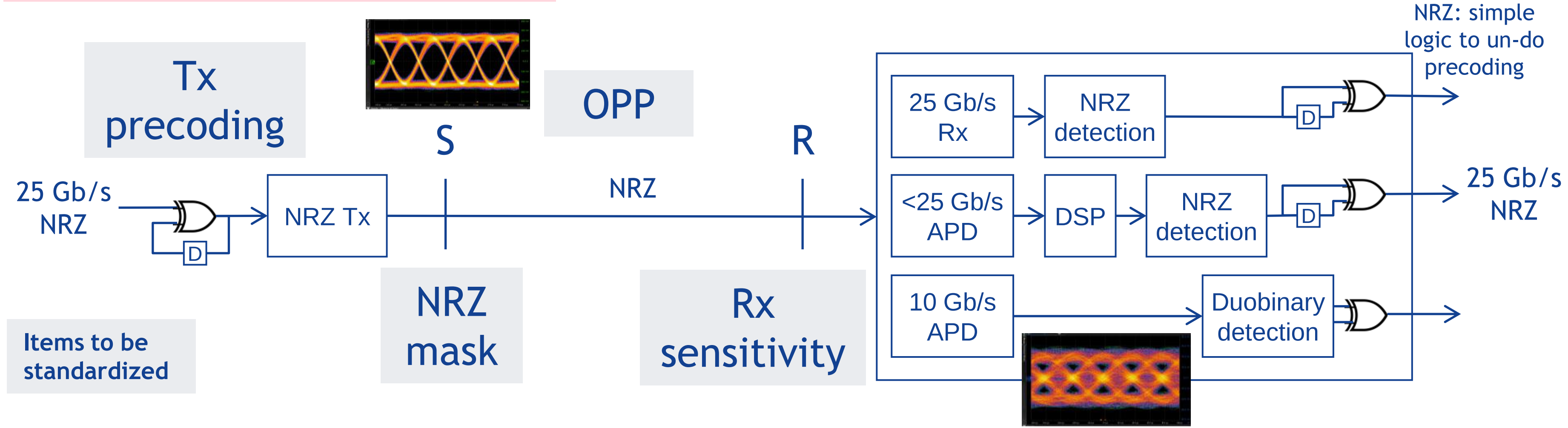
No penalty for dual rate since same 10G BW receiver is used

10G NRZ is detected as 10G NRZ while 25G NRZ is detected as 25G EDB

EDB needs pre-coding, which has to be undone for the other implementations.

This has been discussed before :

REVIEW from ngepon_1511_harstead_1a



- **25 Gb/s Tx**
  - For downstream, cost is shared in the OLT
  - For upstream, only need for symmetrical (premium services)
  - Residential services can be 25G/10G

- **Receiver implementation left to**
  - vendor innovation and
  - evolution of technology.
- **Risk mitigation- no commitment to single solution**
- **No IPR issues**

Pre-coding is not new, it was also previously standardized in IEEE P802.3bj for 100 Gb/s over Backplanes and Copper Cables using PAM4

- Pre-coding for backplanes is used to enable more complex equalizers, based on MLSE (and also DFE), for additional potential performance improvement.
- Inserting pre-coding in IEEE P802.3ca will not only solve error propagation problems for DFE-based EDC and DFE or MLSE-based equalizers using DSP but for electrical duobinary as well.

Figure from IEEE P802.3bj™

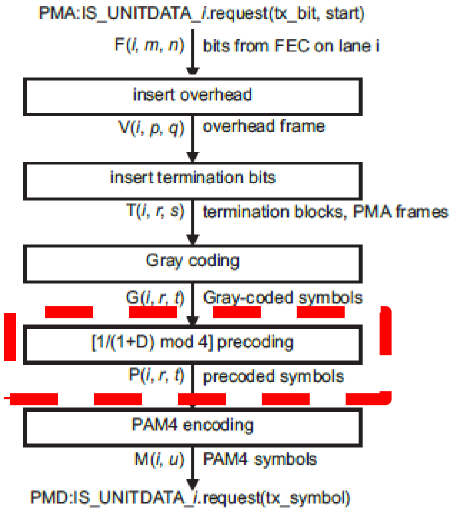
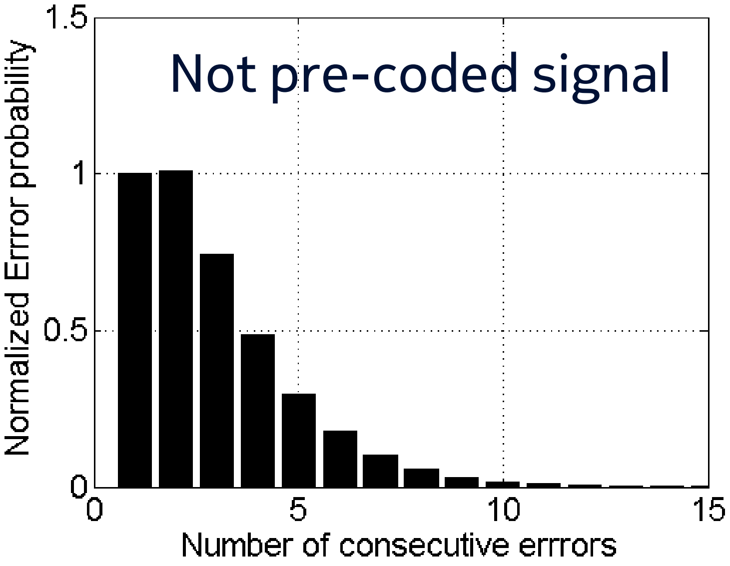
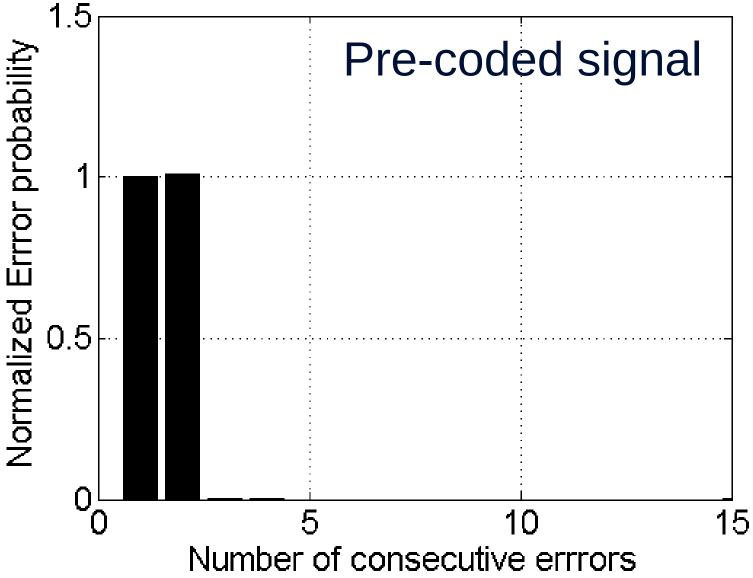


Figure 94–2—Transmit adaptation process diagram

Simulated NRZ error propagation of DFE/MLSE based receivers with and without pre-coding.



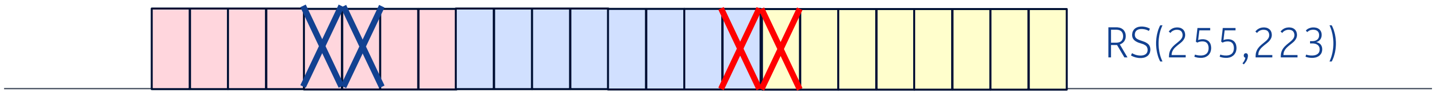


Error distribution using DFE to equalize a 25G NRZ signal detected wit a 10G APD
Pre-coding of the signal avoids ‘catastrophic’ increase in post-FEC BER

Effect of pre-coding on NRZ detection using a 25G APD

- The un pre-coder for the NRZ detection causes each single bit error to be cascaded to the next bit, which causes twin errors.
- **Pre-FEC:**
  - Since most errors are single errors, pre-FEC BER is increased by a factor close to 2, leading to a corresponding pre-FEC optical power penalty.
- **Post-FEC:**
- By using RS-FEC, which is symbol based, most twin errors can be fully corrected, reducing the penalty

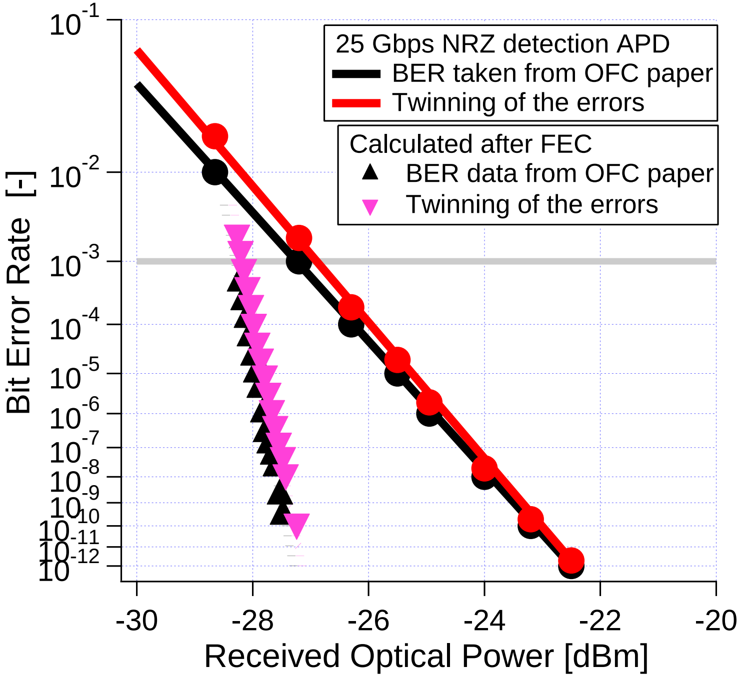
  RS(255,223) (used in 10G-EPON) can correct up to 16 eight-bit symbols per code-word independent of number of errors in the symbol.



Twin errors in in the same symbol (byte), R-S can fully correct

Twin errors span two bytes: two separate single errors must be corrected by R-S

Investigation error propagation for NRZ detection with pre-coding for 25G based APD receiver



Measurements taken from SiFotonics OFC paper of a 25G SiGe APD receiver.

Mengyuan Huang et al. ,"Breakthrough of 25Gb/s Germanium on Silicon Avalanche Photodiode" OFC 2016, Tu2D.2.pdf

0.3 dB optical power penalty observed at 10^{-3}, which will be reduced to 0.1 dB after FEC

It should be noted that RS-codes with longer symbols will reduce the penalty even more after FEC

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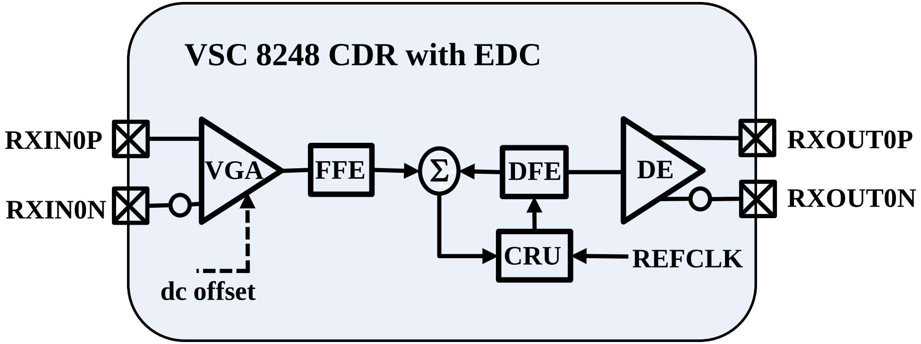
- For 25 Gbps NRZ, dispersion tolerance is reduced significantly compared to 10 Gbps.
- NRZ detection is the least dispersion tolerant, so we might need EDC to enable 20km of fiber transmission.



Since EDC often includes a DFE, it makes pre-coding advantageous for NRZ detection with EDC as well to avoid single errors turning into a long burst of errors.

Conclusions

- Pre-coding enables a unified 25/50/100G EPON architecture.
- It ensures that the most suitable receiver solution (EDB, DSP equalization, 25G NRZ APD) can be deployed at the right time and for the right case.
- Pre-coding is beneficial for EDB, NRZ with EDC and DSP aided NRZ, resulting in only a small penalty after FEC (0.1 dB) for regular NRZ detection only using an 25G APD based receiver.

We believe for risk mitigation it is important to enable an unified architecture with differential pre-coding to avoid error propagation.

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