Options for Single wavelength 50G TDM-PON

Vincent Houtsma, Dora van Veen, Rene Bonk
Nokia, Bell Labs

Study of 50 Gb/s for next generation TDM-PON systems

- In previous meeting there was a request to evaluate the possibility of a single wavelength system with a line rate of 50 Gb/s (wangbo_3ca_2_0717.pdf)

- Main arguments for 50 Gb/s line rate where :

- From a massive deployment point of view, going from 10G to 25G is a too small step as an upgrade
- More and more Ethernet work are based on 50Gb/s per lane, re-use of 200GE and 400GE industry chain is possible
- Reduced complexity of wavelength allocation (50G=1λ, 100G= 2λ instead of 2λ and 4λ's)

We will evaluate the options for 50 Gb/s line rate TDM-PON and show some experimental results

Some different options for single wavelength 50 Gb/s TDM-PON

- NRZ at 50 Gb/s

Requires 50 Gb/s APD or 50 Gb/s SOA-pin at Rx

50 Gb/s EML needed at Tx

50 Gb/s burstmode receiver technology needed for upstream

Dispersion might be a problem at these rates, even in O-band

- PAM4 at 25 Gbaud/s

25 Gb/s APD available from 25G PON can be re-used at Rx

25 Gb/s EML can be used at Tx (needs to be more linear than NRZ)

25 Gb/s burstmode receiver needs to be adopted for PAM4 (3 levels, more linear than NRZ)

- EDB at 50 Gb/s

25 Gb/s APD available from 25G PON can be re-used at Rx

50 Gb/s EML needed at Tx (same as for 50G NRZ)

25 Gb/s burstmode receiver needs to be adopted for EDB (2 levels, more linear than NRZ)

Some different options for single wavelength 50 Gbps TDM-PON

- **Bandwidth limited reception with some form of DSP (50 Gb/s, 25 Gbaud/s)**

EDB, PAM4 with bandwidth limited components and DSP could be used for 50G

Digital signal processing could be used to compensate for limited bandwidth of optical components

Upstream burstmode operation needs to be investigated for this scheme

- **DMT at 50 Gb/s**

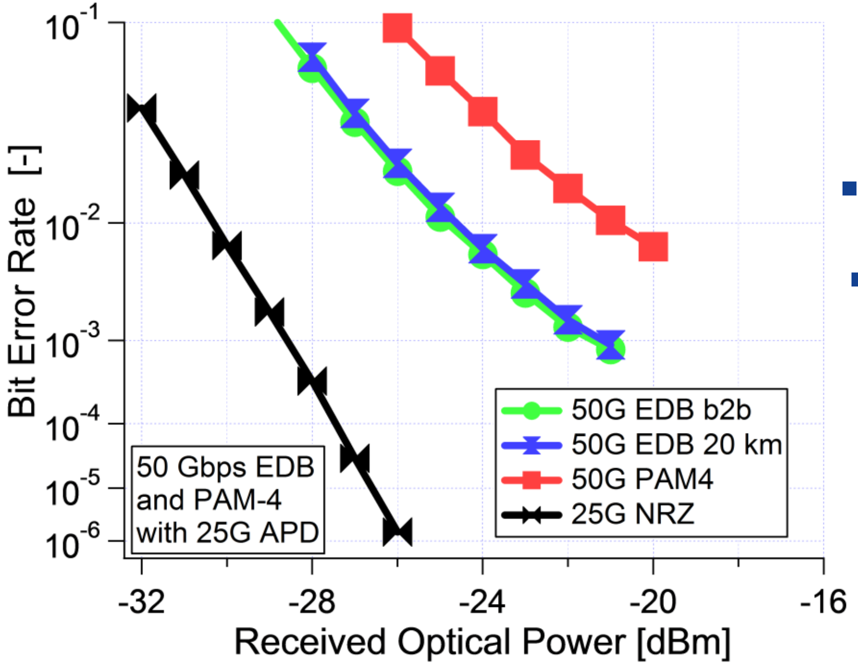
Advantages of DMT is that low cost optics can be used, however complex DSP is needed and linearity requirements of optics are far more stringent than NRZ,EDB and PAM4.

Requires only >10 Gb/s EML and APD

Digital signal processing needed at both transmitter and receiver

Upstream burstmode operation needs to be investigated for this scheme

Measured 50G Downstream EDB and PAM-4 results using 25G APD receiver

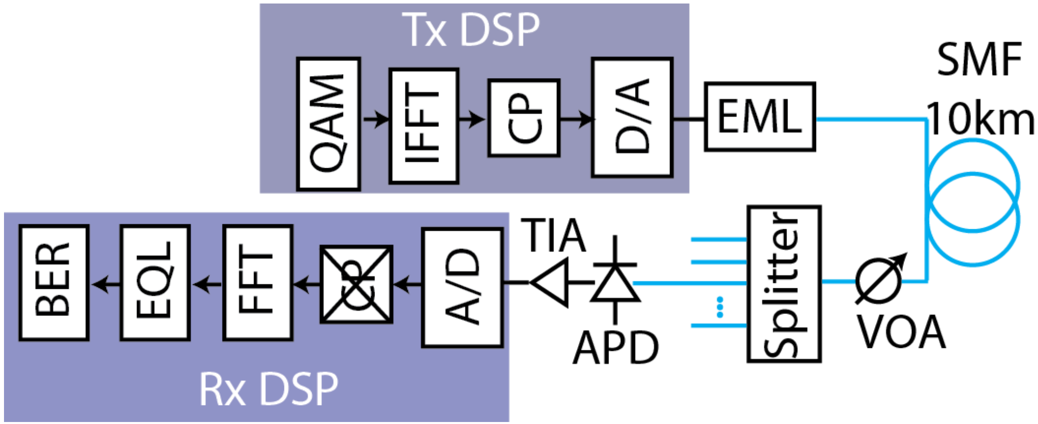


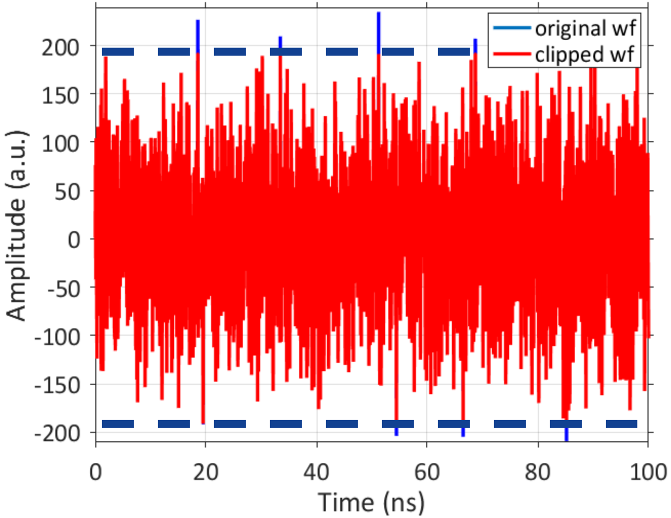
50G Receiver sensitivity using 25G Si/Ge APD

- 4-5 dB penalty between 25G NRZ and 50G EDB
- 50G PAM4 has 4 dB more penalty than EDB
  - EDB = -21 dBm (BER=10^{-3}) =-23.8 dBm (BER=10^{-2})
  - Dispersion penalty of EDB after 20 km SMF is neglectable
  - Used TIA is limiting, further improvement expected with non-limiting TIA

By going from 25G to 50G we loose another 4-5 dB with EDB (8-9 dB for PAM4) which we need to make up for to reach the same 29 dB power budget as for 25G

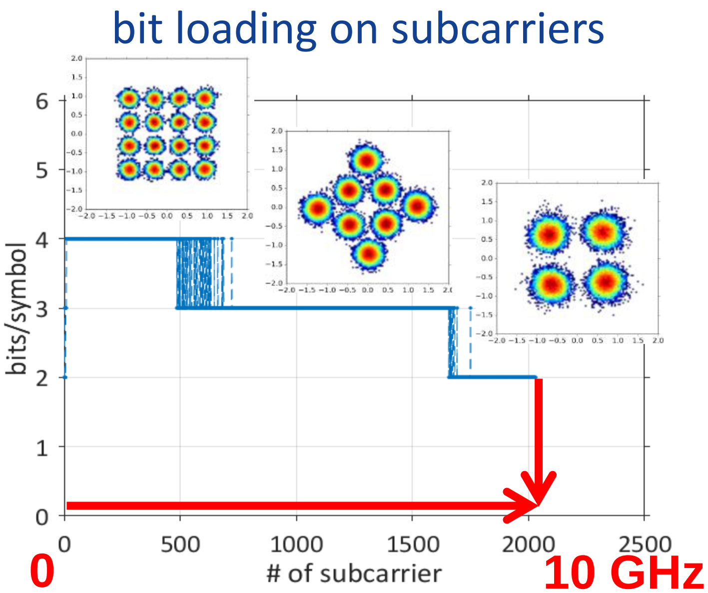
Measurement setup of our >40 Gb/s DMT experiments

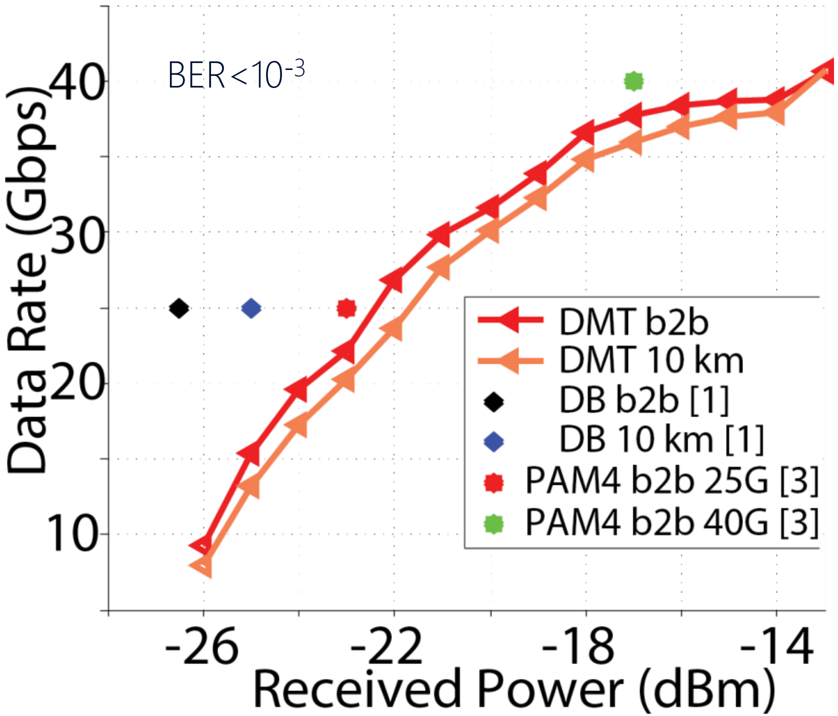




DAC: Fujistu OOLA, 8-bit, sampling frequency 80 GSa/s.
ADC: Keysight DSA Z634A, 8-bit , sampling frequency 80 GSa/s, bandwidth 12 GHz.
EML: MTX510EW 1550nm MQW DFB laser with a small signal bandwidth 10 GHz.
APD: Eudyna ERA1402GT APD, 8GHz 3dB bandwidth, minimum sensitivity -27.5 dBm.

Measurements > 40 Gb/s DMT using 10G EML and 10G APD with bit loading



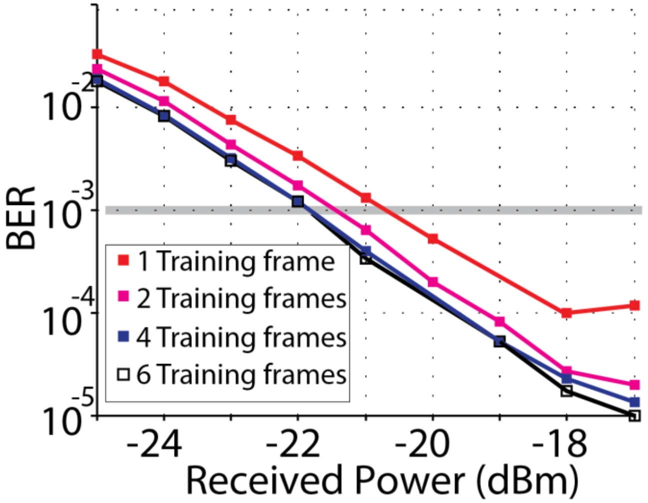


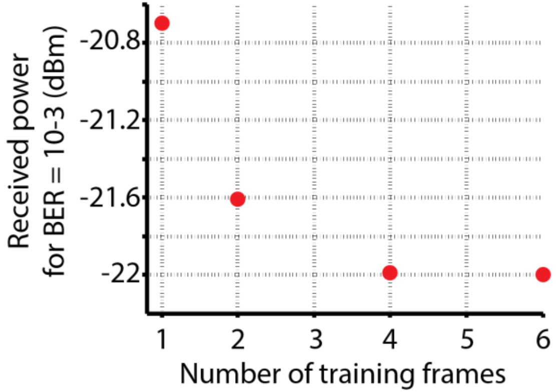
DMT can enable much higher rates with lower speed optics. However power penalty is even larger than EDB and PAM4 when going to 50 Gb/s

[1] V. Houtsma et al., ECOC 2016, paper Th.2.P2.SC7.1
[3] S. Yin et al., OFC 2016, paper Tu3C.2.

NOKIA

DMT upstream burst-mode experiment, vary training sequence length





- Received power vs. training sequence length
- 1 training frame = 200 ns
- 1.3 dB penalty between 200-ns and 1-µs training sequences.
- Starting to converge after 400 ns.

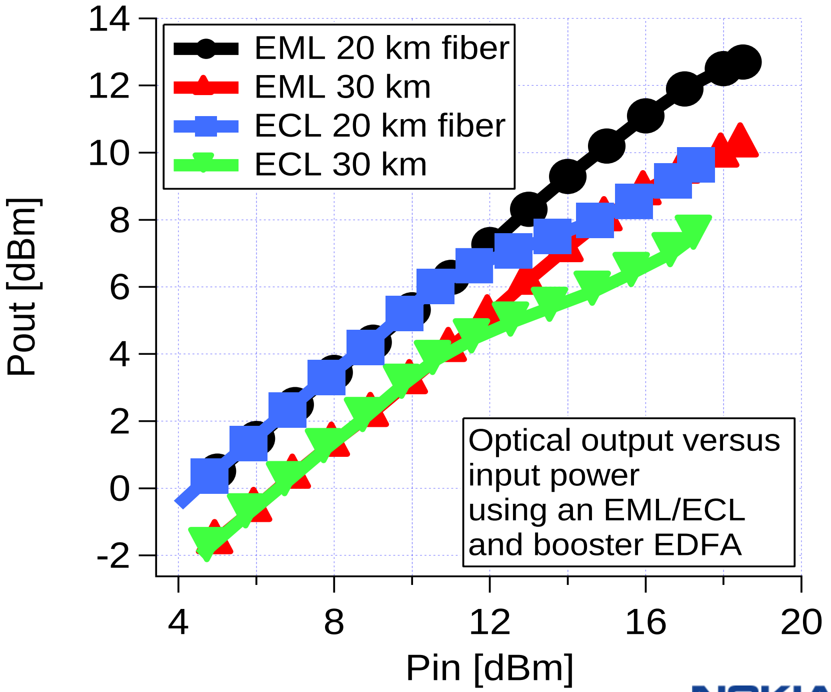
More study needed to investigate if DMT training sequence length in BM can be minimized further.

NOKIA

It is obvious that to reach 29 dB power budget for single wavelength 50 Gb/s TDM-PON some form of optical amplification is needed

- Booster amplifier can be used to launch more optical power

Approximately +10 dBm can be launched into fiber before there will be significant penalty due to fiber non-linearities (stimulated Brillouin scattering, SBS)



NOKIA

Other forms of optical amplification to increase optical power budget

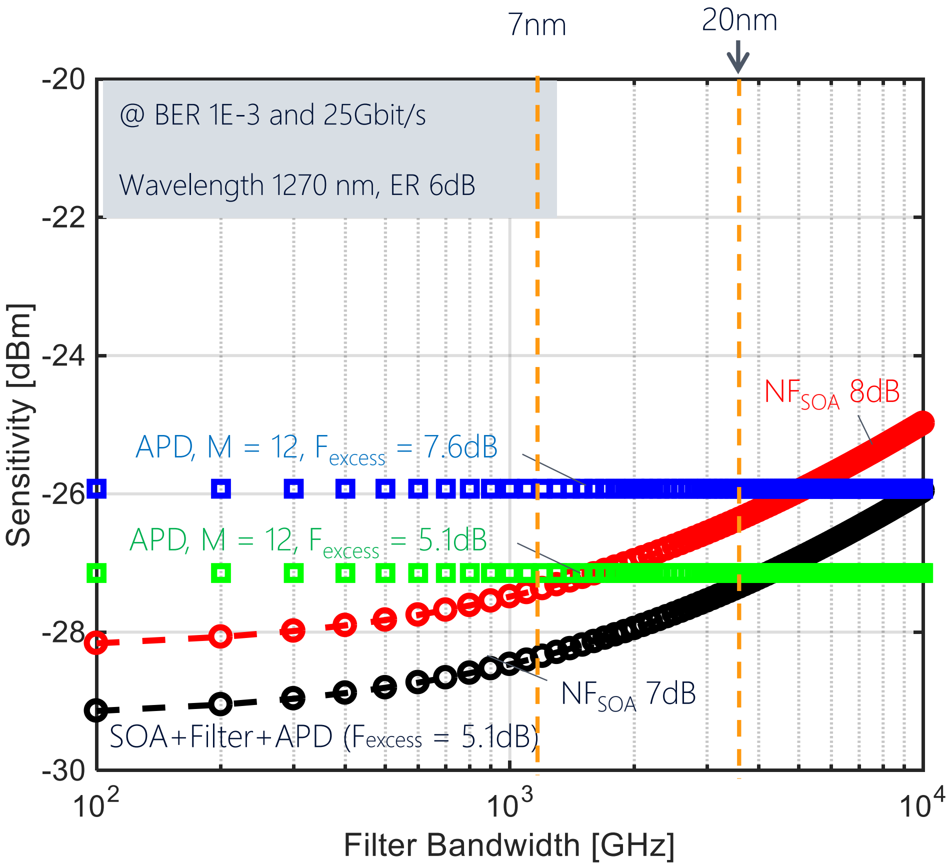
- Pre-amp can be used to increase receiver sensitivity by using SOA-PIN or SOA-APD

However improvement in Rx sensitivity depends on the gain, noise factor and filter bandwidth used.

- Coherent detection can be used to increase receiver sensitivity as well.

Theoretically sensitivity can enhanced up to the shot noise limit, however coherent detection requires close alignment of Tx and LO laser to be within the detector bandwidth and therefore needs more study for PON systems (upstream).

Simulations single wavelength SOA-APD versus APD with M=12 (25G NRZ)



- Rx-filter loss included
- SOA noise figure of 7dB and 8dB
- Si/Ge APD: M = 12 and F_{excess} = 3.22 (5.1dB)
- InAlAs APD: M = 12 and F_{excess} = 5.69 (7.6dB)
- No margins included for aging, etc…

SOA / APD Advantage @ 20nm	
NF = 7dB	F = 7.6dB → 1.4 dB
	F = 5.1dB → 0.1 dB
NF = 8dB	F = 7.6dB → 0.4 dB
	F = 5.1dB → -0.9 dB

SOA / APD Advantage @ 7nm	
NF = 7dB	F = 7.6dB → 2.2 dB
	F = 5.1dB → 1.0 dB
NF = 8dB	F = 7.6dB → 1.3 dB
	F = 5.0dB → 0.1 dB

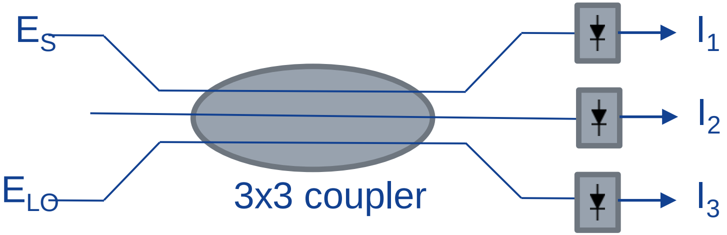
To close the 50G power penalty gap SOA pre-amp gains will bring only limited help

NOKIA

Coherent Receiver Implementation

Implemented using low cost fiber splitter in combination with analog electronics or low complex DSP for reduced power consumption and cost

3x3 coupler has 5 dB loss compared to 8-10 dB for typical coherent receiver
(This is important, since we are concerned about receiver sensitivity, instead of OSNR)



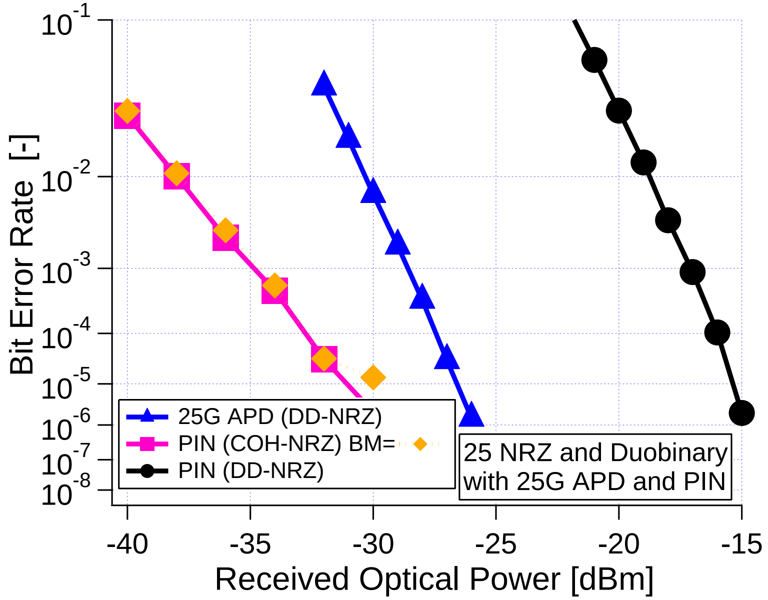
Inphase (I) and quadrature (Q) obtained from :

$$I_I=I_2-0.5I_1-0.5I_3=|E_{LO}||E_S|cos$$
$$I_Q=\sqrt{3}/2(I_3-I_1)=|E_{LO}||E_S|sin\varphi$$

Transmitted NRZ data can be perfectly recovered, without the need for frequency or phase locking after squaring and summing I and Q and low pass filtering with 0.75 times the data rate (typical for a 25G NRZ receiver).

DD and CW LO term are automatically eliminated so no AC-coupling is needed which is beneficial for BM reception

Measurement results Burst-mode upstream : Coherent detection of 25G NRZ



25G Receiver sensitivities at BER=10^{-3}

- DD-NRZ using 25G APD = -28.6 dBm
- COH-NRZ using 11G PIN = -35 dBm

=> -35 dBm equals ~-40 dBm at PD

- Neglectable penalty for 25G COH-BM

11 GHz PINs used, no equalization performed

We achieved a coherent gain of 18 dB

We measured 6.4 dB improvement over APD with DD and 8.5 dB over SOA-PIN* (DD)

* C. Caillaud et al., "High Sensitivity 40 Gbit/s Preamplified SOA-PIN/TIA Receiver Module for High Speed PON" in ECOC 2014

Optical amplification for 50G single wavelength PON to meet power budget :

- Simplest way to make up for reduction in receiver sensitivity at 50G will be to use a booster amplifier at the Tx for instance in the form of an integrated EML+SOA

For 25G target EML Tx power is +5 dBm, so +10 dBm output power of EML+SOA will enable 5 dB gain

- A pre-amp at the Rx (SOA-APD) could be used to further enhance the power budget

  SOA-APD (NF=7, 7nm fltr, M=12, Si/Ge) versus 25G Si/Ge APD (M=12) ~ 1.0 dB

- Coherent detection could be used for the most stringent power classes

  We measured 6.4 dB improvement over APD with DD and 8.5 dB over SOA-PIN (DD)

Conclusions :

- Single wavelength 50 Gb/s is feasible using EDB with 29 dB power budget
- EML+SOA booster amplifier can make up for 4-5 dB penalty going to 50 Gb/s
- Dispersion tolerance at 20 km in O-band is acceptable
- 25 Gb/s APD and burst-mode receiver front-end can be re-used

- PAM4 will have an addition 4 dB power penalty, possibly requiring coherent detection to reach 29 dB class power budgets

- DMT requires even more optical amplification and optical components need to be highly linear as well.

NOKIA